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EVALUATION OF SIZE-SPECIFIC SURVIVAL OF WALLEYE AND CHANNEL CATFISH STOCKED IN A CENTRARCHID-DOMINATED IMPOUNDMENT

January 1, 1986 through August 31, 1996

Final Report to
Illinois Department of Natural Resources

Center for Aquatic Ecology

David H. Wahl, David F. Clapp, and Victor J. Santucci, Jr.

Illinois Natural History Survey
Center for Aquatic Ecology
607 E. Peabody Drive
Champaign, IL 61820

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Center for Aquatic Ecology
Illinois Natural History Survey
R. R. 1, Box 233
Charleston, IL 61920

Final Report

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David H. Wahl
David H. Wahl
Principal Investigator

David Philipp
David Philipp, Director
Center for Aquatic Ecology

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Executive Summary:

This document describes four studies that were conducted at the Ridge Lake Field Station between 1986 and 1995. Study 101a and 102a were initiated in 1986; to evaluate the potential for supplementally stocking walleye to augment sportfish harvest in centrarchid-dominated impoundments (Study 101a), and to evaluate the survival of two sizes of channel catfish stocked in an impoundment containing an established predator population and measure capture efficiencies of various sampling gears (Study 102a). Following personnel changes at Ridge Lake in 1989, these two studies were combined into a revised Study 101b, the objective of which was to develop guidelines for supplemental stockings of walleye and channel catfish in centrarchid-dominated impoundments by quantifying survival, growth, food habits, and harvest resulting from various stocking strategies and by evaluating potential competition with resident centrarchid populations. During the completion of this revised study, gizzard shad were accidently introduced to Ridge Lake from an upstream impoundment. To evaluate this introduction, a new study (Study 102b - "Effect of the introduction of gizzard shad on walleye and centrarchid fish populations") was undertaken from 1993 to 1995.

Throughout this document, the results of the original Studies 101a and 102a are discussed as part of the revised Study 101b, since all the jobs contained in these original studies were incorporated into the revised study. The exceptions to this were Study 101a, Job 1, establishment of fish populations in Ridge Lake and Study 102a, Job 2 efficiency of gears used to collect channel catfish. The objective of this job was to measure the capture efficiencies of some sampling gears available to collect channel catfish in small impoundments, and use the information gained to recommend the most effective tools to use in future studies of catfish in these systems. Electrofishing gear (AC), trot lines, gill nets, and fish traps were used to collect channel catfish in Ridge Lake. Efficiencies were low for all gear types in all years, but gill netting and electrofishing were more effective than other gears for capturing channel catfish. Catfish traps and trot lines appear to catch few fish and select highly for large individuals. The similarity between gill net and angler catch size distributions suggests that, of the gears evaluated, experimental gill nets may be the most appropriate gear for assessing channel catfish population size structure in small impoundments.

The objective of Study 101b (incorporating original Studies 101a and 102a) was to develop guidelines for supplemental stockings of walleye and channel catfish in centrarchid-dominated impoundments. This was done by comparing survival of various sizes of walleye and channel catfish stocked into Ridge Lake; by determining the portion of measured mortality that could be attributed to predation by largemouth bass; by measuring growth and diet of various sizes of stocked walleye; by monitoring catch, harvest, and hooking mortality of walleye and channel catfish; and by evaluating the effect of stocked walleye on centrarchid community structure in Ridge Lake. Most of the results of this work can be found in two journal publications -- Santucci and Wahl (1993) and Santucci et al. (1994) -- that have been included as appendices to this report. We found large walleye fingerlings to have higher survival than smaller fingerlings or fry and that thermal stress at stocking and predation by largemouth bass were more important than hooking mortality or spillway escapement in determining walleye survival. By stocking walleye at least as large a 200 mm in the fall when lake temperatures have declined, we were able to reduce losses to largemouth bass predation and to thermal stress. Although initial costs are substantially higher for these large fingerlings compared with small fingerlings or fry, return on investment increased with walleye size and 200-mm fingerlings were the most economical walleye to stock. Unfortunately, growth of stocked walleye in small impoundments with centrarchid forage will be slower than that of walleye in lakes with other prey populations. Walleye did not appear to influence largemouth bass diets, and because of their relatively low density in Ridge Lake (<22 fish/hectare), walleye probably had little impact on centrarchid abundance and size structure. Because largemouth bass density in Ridge Lake is extremely high relative to walleye density, intraspecific competition for food, rather than interspecific competition, is more likely to be important in determining diet and growth of largemouth bass.

For channel catfish, we found that predation and other sources of mortality, were similar between 200 mm and 250 mm fish. Likewise angler catch and angler harvest, were also similar between 200-mm and 250-mm fish. In addition, return on investment was similar for both size groups. Because 250-mm fish did not have a higher economic return or contribute substantially more to the fishery than the smaller size group, stocking fingerlings larger than 200 mm appears unnecessary for most put-grow-and-take fisheries. However, rearing and stocking larger fish may be beneficial in lakes with an abundance of large predators or where channel catfish growth is slow. Additional efforts to manage channel catfish in small impoundments should focus on optimizing yield by regulating angler exploitation. High exploitation rates and low hooking mortality of all sizes of fish suggest that protective size limits may be useful in deferring fishing mortality, thus increasing the size of fish available for harvest without substantially reducing numerical harvest. Further studies are needed to determine the specific effects of harvest restrictions on stocked channel catfish populations.

In the revised Study 102b, begun in 1993, we sought to determine the impact of the introduction of gizzard shad on resident centrarchid populations and stocked walleye in a small impoundment, and to make management recommendations regarding manipulation of forage and game fish populations. Gizzard shad introduction appeared to have had a substantial negative impact on centrarchid survival, possibly through competition for food or interference with spawning activities. In contrast, gizzard shad had little influence on overall walleye survival, but may have influenced predation mortality. Density of forage fish other than gizzard shad (i.e., centrarchids) had more of an influence on walleye survival. Additionally, gizzard shad introduction led to major shifts in diet of walleye and to slight improvements in growth. Growth of centrarchid species did not appear to be affected positively or negatively.

Gizzard shad had no observable positive impact on catch, harvest, and growth of primary sport fish species in Ridge Lake, but may have negatively influenced largemouth bass catch. In general, the effects of introducing gizzard shad may be positive or negative, depending on the target species and population attribute of interest. With this in mind, introduction of gizzard shad to improve sport fish populations should be undertaken only with caution and after careful consideration of management objectives.

Study 101a. Evaluation of stocked walleye in small, centrarchid-dominated impoundments.

Objective: To evaluate the potential for supplementally stocking walleye to augment sportfish harvest in centrarchid-dominated impoundments.

Job 101.1 Establishing fish populations in Ridge Lake

Objective: To stock into Ridge Lake adequate numbers and sizes of largemouth bass, bluegill, and black crappie to approximate the size structure and biomass of mature populations.

Introduction: Common stocking strategies implemented in new or renovated impoundments frequently result in the immediate production of very strong year classes of one or more species. These year classes subsequently may dominate the sport fish harvest, delay for years the development of a stable population age structure, and produce undesirable predator-prey ratios. The objective of this job was to stock adequate numbers and sizes of largemouth bass Micropterus salmoides, bluegill Lepomis macrochirus, and black crappie Pomoxis nigromaculatus, to produce mature population age structures. The intent of this stocking strategy was to prevent the formation of dominant year classes by providing predation pressure on the young-of-the-year produced in 1986. In the case of black crappie, the strategy was to prevent the formation of a dominant year class by delaying stocking until the spawning season was over. The early establishment of a mature population should also accelerate the development of a quality sport fishery, as well as provide more realistic predation pressure on stocked walleye Stizostedion vitreum and channel catfish Ictalurus punctatus.

Procedures: Fish stocked into Ridge Lake were secured from a number of sources, including Little Grassy State Fish Hatchery, Sam Parr Biological Station, and numerous central Illinois impoundments. Fish were collected from impoundments by electrofishing or trap netting and were transported to Ridge Lake in water aerated with pure oxygen. Salt (0.5%) and acriflavin (2 ppm) were added to reduce stress and bacterial infection, respectively. Small young-of-the-year fish obtained from Little Grassy State Fish Hatchery were transported in plastic bags containing water saturated with pure oxygen.

Findings: Largemouth bass, bluegill, and black crappie were stocked into Ridge Lake throughout the spring, summer, and fall of 1986. Age-I bass (N=478) were provided by Little Grassy State Fish Hatchery and age-I and older bass (N=675) were obtained from five Illinois lakes (Table 1). Lengths of largemouth bass collected for stocking varied over a wide range (100-510 mm) to approximate the size structure of a mature population (Table 2).

Largemouth bass spawned successfully in Ridge Lake during 1986.

Bluegill, ranging in length from 30 to 200 mm, were stocked into Ridge Lake from April through July 1986 (Table 2). Age-I bluegill (N=3,000) were provided by Little Grassy State Fish Hatchery and age-I and older fish (N=1,451) were obtained from five lakes (Table 1). Bluegill spawned successfully in Ridge Lake during 1986.

Adult black crappie (N=246), obtained from three lakes (Table 1), were stocked into Ridge Lake (June-October 1986) after the 1986 spawning period was complete. Age-0 black crappie stocked in 1986 were provided by Little Grassy State Fish Hatchery (N=5,300; mean length=18 mm) and Sam Parr Biological Station (N=115; mean length=69 mm). The success of the initial age-0 crappie stocking (N=5,300) was evidenced by the capture of several of these fish in gill nets at the end of the first summer following stocking.

Two size groups of channel catfish were stocked into Ridge Lake on 25 August 1986 (Table 2). These fish (N=750) were provided by Little Grassy State Fish Hatchery.

Study Summary: Job 1 was completed on schedule and fish populations were successfully established in Ridge Lake to allow for completion of the other jobs of this study. These jobs (2-10) were incorporated into a revised Study 101b, beginning in 1990, and a summary of the results of this work is presented below.

Study Recommendations: See revised Study 101b below.

Table 1. Sources of fish stocked into Ridge Lake during 1986.

Species	Source
Largemouth bass, <u>Micropterus salmoides</u>	Little Grassy Hatchery, Williamson Co. Mill Creek, Clark Co. Ramsey Lake, Fayette Co. Wyman Lake, Moultrie Co. Woods Lake, Moultrie Co. Lake Shelbyville, Moultrie Co.
Bluegill, <u>Lepomis macrochirus</u>	Little Grassy Hatch Williamson Co. Mill Creek, Clark Co. Forbes Lake, Marion Co. Coles Co. Airport, Coles Co. Woods Lake, Moultrie Co. Lake Shelbyville, Moultrie Co.
Black crappie, <u>Pomoxis nigromaculatus</u>	Little Grassy Hatchery, Williamson Co. Sam Parr Biol.Sta., Marion Co. Coles Co. Airport, Coles Co. Rend Lake, Franklin Co.
Channel catfish, <u>Ictalurus punctatus</u>	Little Grassy Hatchery, Williamson Co.

Table 2. Lengths, numbers, and weights of fish stocked into Ridge Lake during 1986.

Species and sizes (mm)	Number stocked	Total wt. (kg)	No./ ha	kg/ ha	Mean TL (mm)
Largemouth bass					
100-159	699	14	125	2	118
160-299	358	87	64	16	255
300-509	96	60	17	11	343
Bluegill					
30-79	3,039	3	543	<1	42
80-199	1,412	83	252	15	138
Black crappie					
10-79	5,415	1	967	<1	19
80-210	246	27	44	5	188
Channel catfish					
180-219	375	18	67	3	192
240-269	375	56	67	10	253

Study 102a. Survival of stocked channel catfish and the efficiency of some sampling gears available to collect them.

Objective: To evaluate the survival of two sizes of channel catfish stocked in an impoundment containing an established predator population and measure capture efficiencies of various sampling gears.

Job 102.2 Efficiency of gears used to collect channel catfish

Objective: To measure the capture efficiencies of some sampling gears available to collect channel catfish in impoundments.

Introduction: Knowledge of gear efficiency is necessary to evaluate the abundance of channel catfish stocked in impoundments. However, population size must be known to accurately calibrate gear efficiency. At Ridge Lake, the number of channel catfish stocked each year is known and survivors from earlier stockings were determined by mark-recapture methods.

Procedures: Electrofishing gear (AC), 4 trot lines, 2 gill nets, and 10 fish traps were used to collect channel catfish in Ridge Lake. Two day and two night shoreline electrofishing samples were made in September. Sampling with fixed entrapment gears, deployed at various locations throughout the lake, was initiated in late September and continued through October. All captured channel catfish were measured, examined for fin clips, and returned to the lake.

Each electrofishing sample consisted of one trip around the perimeter of the lake (56-96 min). Trot lines (50 ft long, 20 hooks per line) were baited (chicken livers or leeches in 1987; cut-up dead fish in 1988 and 1989) and fished perpendicular to the shoreline. Experimental monofilament gill nets (150 ft long x 6 ft deep), consisting of six 25-ft panels with meshes of 0.75-, 1.0-, 1.25-, 1.5-, 1.75-, and 2.00-in. bar mesh, were set perpendicular to the shoreline in 7-21 ft of water. All gill net sets were bottom sets. Cylindrical fish traps, fitted with a funnel at one end, were baited with cheese bait and fished in 2-20 ft of water. Of the 10 traps used in 1987, two were wooden slat traps (4 ft long, 10 in. diameter) and eight were constructed of 0.5-in. mesh plastic coated hardware cloth (4 ft long, 1-ft diameter). Five wooden and five wire traps were used in 1988 and 1989; traps were deployed in pairs with one of each type of trap at a location. Trot lines and fish traps were examined for fish and rebaited once each day and at 3-7 day intervals, respectively. Gill nets were checked 5 times a day (approximately 0800, 1100, 1400, 1700, and 2100 hours) in an attempt to reduce losses of channel catfish and non-target species.

Capture efficiency for a gear is defined as the percentage of catfish present in the lake that are captured in a unit of sampling effort. A unit of sampling effort is defined for electrofishing gear as 1-h of sampling, and for the fixed entrapment gears, as a 24-h set of a single unit of gear. Catfish population estimates are presented in Table 3.

Findings: Mean capture efficiencies did not exceed 2.5% for all gears used in 1987, 1988, and 1989 (Table 4). Although efficiencies were low in all years, gill netting and electrofishing were more effective than other gears for capturing channel catfish. However, comparisons of different gears based on capture efficiency are difficult due to the differing effort required for each gear. For example, one unit of effort for gill nets (checked 5 times/day) required substantially more man-h than a unit of effort for catfish traps (checked at 3-5 day intervals). Furthermore, while similar numbers of fish were caught in gill nets (N = 57) and wooden slat traps (N = 47) in 1988, gill net efficiency values were much higher because fewer gill nets (N = 2) were fished than catfish traps (N = 5). Wire mesh traps were not included in this comparison because they were ineffective at capturing fish; only 8 catfish were collected in 1987-1989 (effort = 571 trap-days).

Gear efficiency estimates for age-II and older channel catfish decreased from 1987 to 1988 despite the higher estimated abundance of catfish in 1988 (N for 1988 = 398, N for 1987 = 104). In contrast, catch-per-unit-efforts of most gears increased in 1988 and, in accordance with changes in abundance of age-II and older catfish (Table 3), decreased in 1989 (Table 5). Year to year variability in channel catfish population size may not have been accurately reflected in the gear efficiency estimates because the portion of the catfish population sampled in a single unit of effort for a given gear was extremely low (< 3%). Capture efficiencies of small catfish (< 12-in., age-I fish stocked the year of the sample) were extremely low for all gears tested in 1987- 1989 (< 0.6%). These low values suggest that these gears are not suitable for assessing the abundance of small catfish.

The size structure of the catfish population may affect gear efficiency estimates because most sampling methods are size selective. In Ridge Lake, length distributions of channel catfish captured by each gear were different (Kolmogorov-Smirnov Test, $P < 0.05$) and there was an increase in the size of catfish captured by electrofishing, gill nets, wooden traps, and trot lines, respectively (Fig. 1). Size distributions for each gear also differed significantly from the distribution of channel catfish caught by anglers in the fall (Kolmogorov-Smirnov Test, $P < 0.05$), except for the gill net distribution which was similar (Kolmogorov-Smirnov Test, $P = 0.45$).

Study Summary: Catfish traps and trot lines appear to catch few fish and select highly for large individuals. Gill netting and electrofishing appear to be more useful methods for sampling catfish. The similarity between gill net and angler catch size distributions (even though sample sizes were still small) suggests that, of the gears evaluated, experimental gill nets may be the most appropriate gear for assessing channel catfish population size structure in small impoundments.

Jobs 1 and 3 of the original Study 102a were incorporated into a revised Study 101b, beginning in 1990, and a summary of the results of this work is presented below.

Study Recommendations: See Study 101b.

References:

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Table 3. Estimated population sizes of age-1 and older channel catfish in Ridge Lake, fall 1987-1989. The Chapman modification of the Peterson formula (Ricker 1975) was used to estimate population size; 95% confidence intervals are in parentheses. Missing values represent years in which the number of recaptures (R<3) was insufficient to calculate population estimates. Population size of newly stocked age-1 channel catfish was assumed equal to the number of fish stocked minus harvest losses.

Year	Age-1	Age-2 and older
1987	714	104 (37-208)
1988	733	398 (206-837)
1989	725	---

Table 4. Mean efficiencies of gears used to collect age-I and older channel catfish at Ridge Lake during fall 1986-1989. Channel catfish were stocked as age-I fish each summer from 1986 through 1989. Gear efficiency = (catch-per-unit-effort (CPUE)/population size) x 100. Effort is defined for electrofishing gear as 1-h of sampling, and for fixed entrapment gears as a 24-h set of a single unit of gear.

	Electrofishing			Catfish traps		
Year	Day	Night	Gill nets	Wooden slat	Wire mesh	Trot lines
			Age-I			
1987	0	0.36	0.04	0	<0.01	0
1988	0.38	0.36	0.10	<0.01	<0.01	0
1989	0.10	0.51	0.04	<0.01	0	0
Average	0.16	0.41	0.06	<0.01	<0.01	0
			Age-II and older[a]			
1987	1.20	2.49	0.71	0.26	0.02	0.14
1988	0.70	0.36	0.35	0.06	0	0.08
Average	0.95	1.42	0.53	0.16	0.01	0.11

[a]Efficiency estimates for age-II and older catfish could not be computed in 1989 because insufficient recaptures precluded the calculation of a population estimate for these fish.

Table 5. Average number caught and average catch-per-unit-effort (CPUE) of age-I and older channel catfish collected with various gears at Ridge Lake, fall 1987-1989. Channel catfish were stocked as age-I fish each summer from 1986 through 1989. Effort is defined for electrofishing gear as 1-h of sampling, and for fixed entrapment gears as a 24-h set of a single unit of gear.

	Electrofishing				Gill nets		Slat traps		Trot lines	
	Day		Night							
Year	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
					Age-I					
1987	0	0	7	2.6	12	0.3	0	0	0	0
1988	7	2.8	6	2.7	19	0.7	5	<0.1	0	0
1989	2	0.7	6	3.7	9	0.3	1	<0.1	0	0
Average	3	1.2	6.3	3.0	13.3	0.4	2	<0.1	0	0
					Age-II and older					
1987	3	1.2	7	2.6	28	0.7	16	0.3	5	0.1
1988	7	2.8	3	1.3	38	1.4	42	0.2	23	0.3
1989	1	0.4	2	1.2	23	0.7	2	<0.1	11	0.2
Average	3.7	1.5	4	1.7	29.7	0.9	20	0.2	13	0.2

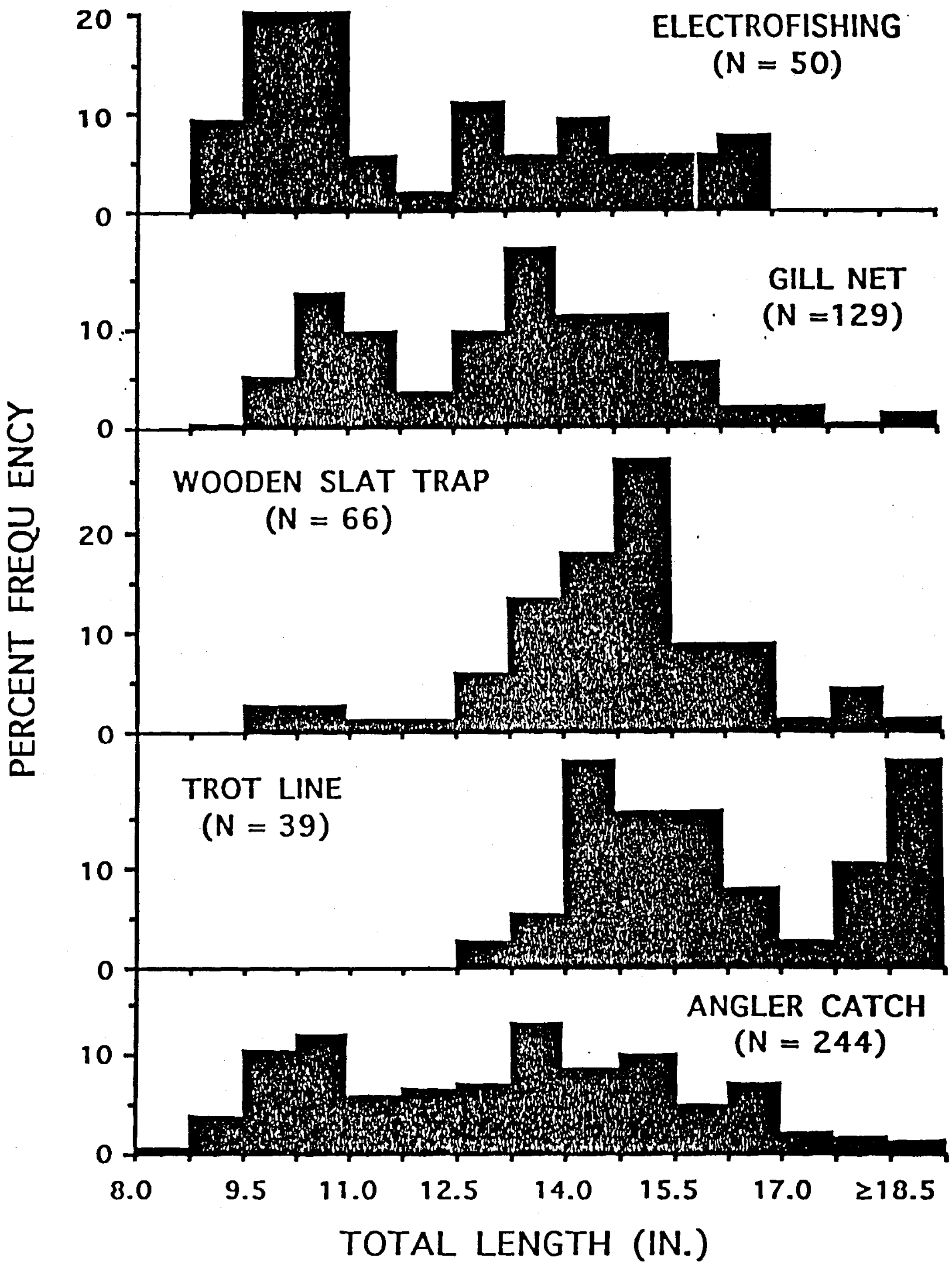

Fig. 1. Length frequency distributions of channel catfish sampled with electrofishing gear, gill nets, wooden slat traps, trot lines, and the angler catch during September and October at Ridge Lake. Values represent combined data from 1987, 1988, and 1989.

Study 101b. Evaluation of size-specific survival of walleye (*Stizostedion vitreum*) and channel catfish (*Ictaluris punctatus*) stocked in a centrarchid-dominated impoundment.

Objective: To develop guidelines for supplemental stockings of walleye and channel catfish in centrarchid-dominated impoundments by quantifying survival, growth, food habits, and harvest resulting from various stocking strategies and by evaluating potential competition with resident centrarchid populations.

Job 101.1 Size-specific survival of stocked walleye and channel catfish.

Objective: To compare survival of various sizes of walleye and channel catfish stocked into a centrarchid-dominated impoundment.

Introduction: The potential for supplementary stocked walleye to contribute to the sport fishery of warmwater impoundments depends substantially on survival rates of stocked fish. The survival of various sizes of stocked fry and fingerling walleye has been estimated frequently (Laarman 1978), but not in small centrarchid-dominated impoundments. Maximum benefits are realized when walleye fingerlings are stocked at a size that provides the greatest return to the creel per dollar spent on rearing. Herein, we evaluate survival of walleye fry and three sizes of fingerlings stocked into an impoundment containing an established centrarchid population.

Recruitment of channel catfish in small impoundments is often poor to nonexistent (Marzolf 1957, Davis 1959). As a result, restocking must occur at intervals to sustain an acceptable sport fishery. However, the survival of supplementary stocked fish may also be poor when established largemouth bass populations are present (Crance & McBay 1966, Mestl 1983). Mortality of stocked channel catfish can be reduced by stocking larger fish (Krummrich & Heidinger 1973, Powell 1975, Mestl 1983), but rearing costs increase with fish size (American Fisheries Society 1982). A previous study at Ridge Lake demonstrated that the greatest return on investment was obtained by stocking catfish at least as large as 203 mm TL (Storck & Newman 1988). This job, in part, was an extension of that study, comparing the survival and harvest of channel catfish stocked as 8- and 10-inch fingerlings into an impoundment containing an established largemouth bass population.

Procedures and Findings: Results of work conducted in this job are reported in Appendix A, Santucci and Wahl. 1993. Factors influencing survival and growth of stocked walleye (Stizostedion vitreum) in a centrarchid-dominated impoundment, published in the Canadian Journal of Fisheries and Aquatic Sciences 50:1548-1558, and Appendix B, Santucci et al. 1994. Growth, mortality, harvest, and cost-effectiveness of stocked channel catfish in a small impoundment, published in the North American Journal of Fisheries Management 14: 781-789.

Job 101.2 Zooplankton-walleye fry relationships.

Objective: To determine the relationship between zooplankton density and survival and growth of stocked walleye fry.

Introduction: Walleye fry are often chosen over fingerlings for lake stockings because large numbers of fry can be produced and stocked at relatively low costs. However, success of fry stockings can be highly variable (Laarman 1978, Hanson et al. 1976). An understanding of the factors responsible for this high year-to-year variability is critical to developing effective stocking strategies. In this job, we assessed the importance of zooplankton density in determining the success of fry stockings by monitoring zooplankton abundance in Ridge Lake. We also conducted controlled tank experiments to evaluate walleye fry and zooplankton interactions.

Procedures: To determine the relationship between zooplankton density and the survival and growth of walleye fry, we established low, medium, and high zooplankton densities in each of 12 circular tanks (5,621 l/tank, 4 replicates for each density). Initial zooplankton densities were established by filling tanks with water from an adjacent pond which was artificially enriched with nutrients to create a high zooplankton biomass. Tanks were filled with unfiltered water (high density), 50% filtered water (medium density), and 90% filtered water (low density). Filtered water was passed through a 64 μm mesh plankton net. Each tank was stocked with 4-d old walleye fry (N=200).

Walleye growth and zooplankton abundance and diversity were monitored at three to four day intervals over a two-week period. To monitor zooplankton abundance and diversity, water samples were collected from the entire water column with a 76-mm diameter acrylic tube and filtered through a 64 μm mesh screen. Filtered water was returned to the tanks and the condensed zooplankton sample preserved in a 10% formalin/sucrose solution. Zooplankton abundance and diversity were derived by identifying and enumerating the total zooplankton in three random 1 ml subsamples from each condensed sample. Walleye fry were collected by light trapping and 5 fish preserved from each tank on each sampling date to monitor growth rates. Total lengths were measured with the aid of a microscope to the nearest 0.01 mm; stomach contents were identified, enumerated, and measured (nearest 0.01 mm).

Zooplankton density and species composition in Ridge Lake were monitored at biweekly intervals from April through September. Vertical zooplankton tows were made at 3 sampling stations using a 0.5 m, 64 um mesh zooplankton net. Samples were preserved in a 10% formalin/sucrose solution. In the laboratory, samples were adjusted to a constant volume (100 ml) and subsampled by 1 ml (1/100) aliquot. Numbers of major groups of zooplankton (Cladocerans, Copepods, Copepod nauplii, and Rotifers) were identified and counted under a dissecting microscope.

Findings: The zooplankton in the experimental tanks was comprised primarily of three taxonomic orders; Cladocera, Copepoda, and Rotifera (Figure 2). There was no difference in diversity of zooplankton in the three treatments (repeated measures ANOVA, $p \geq 0.09$). The relative abundance of zooplankton remained consistent in the low, medium, and high density tanks throughout the experiment with the exception of a decline in the medium density tanks on May 6 (Figure 3). Zooplankton abundance was highest in the tanks stocked with the high zooplankton levels followed by the medium and low density tanks (repeated measures ANOVA, $p \leq 0.035$)

Walleye growth rates in the individual tanks were closely correlated with total zooplankton density (Figure 4). Walleye grew faster in the high zooplankton density tanks followed by the medium and low density tanks (Figure 5; repeated measure ANOVA, $p \leq 0.031$). When compared with the abundance of individual taxonomic orders, walleye growth was correlated most closely with numbers of cladocerans, and showed little relationship to the density of Copepods or Rotifers (Figure 6).

Walleye mortality rates declined with increasing zooplankton abundance (Figure 7). Mortality was high for all three treatments, averaging 72% in the high density tanks, 81% in the medium density tanks and 88% in the low density tanks. Differences in the mortality rates of the three treatments were significant only between the low and high density tanks (one-way ANOVA, Fisher's PLSD, $p = 0.0077$).

Walleye in all three treatments (low, medium, and high zooplankton density) consumed fewer and larger prey through time. Walleye consumed greater numbers and weights of prey in the medium and high density tanks than in the low density tanks during the first six days after stocking (Figure 8). However, after 9 days fish in the low density tanks were consuming more prey than in the other treatments. This increased consumption in the low density tanks was the result of shifts in the diet to increased numbers of chironomid prey items (Figure 9). Walleye began consuming chironomids earlier in tanks with low zooplankton densities (Figure 10). Chironomids replaced zooplankton as the primary component of the diet after 6 days in the low zooplankton density tanks and after 13 days in the medium density tanks. The shift from zooplankton to chironomids in the diets corresponded to periods of slower growth (Figure 5), and suggests that either lower energetic values or higher capture costs make chironomids a less efficient food item for larval walleye.

Examination of zooplankton samples from Ridge Lake indicated that zooplankton was abundant during the time of walleye fry stocking (Figure 11). Copepod density peaked in early-to mid-April at approximately 150 organisms/l, and peak cladoceran density (approximately 100 organisms/l) occurred in early May. While density of large zooplankters remained at a level (greater than 50 organisms/l) that, based on laboratory experiments, should have ensured the highest survival and best growth of stocked walleye fry, survival of fry was extremely poor (Appendix A.). This uniformly poor survival prevented us from evaluating the relationship between zooplankton density and walleye fry survival. Based on these results, water conditions (i.e., turbidity) or other factors such as predation probably are more important than zooplankton populations in determining walleye fry survival in Ridge Lake.

Job 101.3 Growth and food habits of walleye.

Objective: To determine growth rates and food habits of various sizes of walleye stocked in a centrarchid-dominated impoundment.

Introduction: Growth of walleye is an important factor influencing management strategies in centrarchid-dominated impoundments. Although estimates of walleye growth in small centrarchid-dominated impoundments are rare, walleye have been shown to readily eat bluegill when they are the predominant fish species available as forage (Schneider 1975, Beyerle 1978). However, in both of these studies, walleye grew more rapidly with minnow forage than with bluegill forage. The purpose of this job was to evaluate the growth rates and food habits of walleye fry and three size groups of fingerlings stocked into Ridge Lake, a centrarchid-dominated system.

Procedures and Findings: Results of work conducted in this job are reported in Appendix A, Santucci and Wahl. 1993. Factors influencing survival and growth of stocked walleye (Stizostedion vitreum) in a centrarchid-dominated impoundment, published in the Canadian Journal of Fisheries and Aquatic Sciences 50:1548-1558

Job 101.4 Predator mortality of walleye and channel catfish.

Objective: To determine the vulnerability of various sizes of walleye and channel catfish to largemouth bass predation.

Introduction: Supplementary stocked species, such as walleye and channel catfish, often suffer high mortality in impoundments containing established predator populations. To determine the importance of predation as a cause of this mortality, we examined the food habits of potential predators (largemouth bass, walleye, and black crappie) of the stocked species.

Procedures and Findings: Results of work conducted in this job are reported in Appendix A, Santucci and Wahl. 1993. Factors influencing survival and growth of stocked walleye (Stizostedion vitreum) in a centrarchid-dominated impoundment, published in the Canadian Journal of Fisheries and Aquatic Sciences 50:1548-1558, and Appendix B, Santucci et al. 1994. Growth, mortality, harvest, and cost-effectiveness of stocked channel catfish in a small impoundment, published in the North American Journal of Fisheries Management 14: 781-789.

Job 101.5 Catch, harvest, and hooking mortality of walleye and channel catfish.

Objective: To determine catch, harvest, and hooking mortality of various sizes of stocked walleye and channel catfish.

Introduction: Increased harvest rates and greater diversity in the creel are major goals of sport-fish management. A management tool often employed to attain these goals is the introduction of additional game-fish species (e.g., walleye, muskellunge) into an existing sport fishery. The success of these introductions ultimately rests on the contribution of the stocked species to the creel and their impact on the catch and harvest of other sport fish. In this job, a creel census was used to evaluate the impact of walleye and channel catfish on the catch and harvest of fish in Ridge Lake.

Procedures: Fishing at Ridge Lake was by permit only and the lake was open 5 days a week (2 sessions daily, 0600-1000 hours and 1500-2000 hours; closed Mondays and Tuesdays) during late April through mid-October. A single entry point was used to gain access and only boat fishing (maximum of 8 boats, 3 persons each) was allowed. Angling effort, total catch, and harvest were recorded for each fishing party. Largemouth bass, bluegill, black crappie, and channel catfish were held in boat live wells and retrieved at a lake-side laboratory where they were measured in total length (nearest mm) and weighed (nearest g). Sublegal and unwanted fish were returned to the lake. A 14-inch minimum length limit was in effect throughout the study for largemouth bass and walleye, and beginning in 1990 for channel catfish.

Anglers were given flags to indicate that a walleye had been caught. Walleye were retrieved immediately and sublegal and unwanted fish were placed in a floating creel (see previous description of fingerling cages in Job 1) to determine hooking mortality. Sublegal and unwanted channel catfish were also held in floating creels. After holding overnight (12-15 h), walleye and channel catfish were measured, weighed, and checked for fin clips and survivors were returned to the lake.

Findings: Results of work conducted in this job are reported in Appendix A, Santucci and Wahl. 1993. Factors influencing survival and growth of stocked walleye (Stizostedion vitreum) in a centrarchid-dominated impoundment, published in the Canadian Journal of Fisheries and Aquatic Sciences 50:1548-1558, and Appendix B, Santucci et al. 1994. Growth, mortality, harvest, and cost-effectiveness of stocked channel catfish in a small impoundment, published in the North American Journal of Fisheries Management 14: 781-789. Supplemental information collected during the creel census that was conducted as part of this job was presented in Santucci, V.J., Jr., and Wahl, D.H. 1991. Use of a creel census and electrofishing to assess centrarchid populations, American Fisheries Society Symposium 12:481-491.

Job 101.6 Effect of stocked walleye on centrarchid community structure.

Objective: To evaluate the impact of stocked walleye on bluegill and largemouth bass populations.

Introduction: The success of supplementary stocked predators is judged, in part, by the predator's impact on prey populations. In small impoundments, largemouth bass predation is often inadequate to control bluegill abundance. Predation by supplementary stocked walleye may reduce bluegill density and thus improve the population growth and size structure of this prey species. Growth, relative weight (W_r), and proportional stock density (PSD) of bluegill were monitored in Ridge Lake and were compared with historical data to evaluate the impact of walleye on bluegill populations. In addition, we monitored the food habits of largemouth bass, walleye, and black crappie to assess the potential for interspecific competition and thus the compatibility of these species in small impoundments.

Procedures: Bluegill were collected at night in September, October, and November by electrofishing (AC) along the entire perimeter of the lake. All fish were measured (nearest 1-mm) and fish >100 mm were weighed (nearest g). Ages of bluegill >25 mm were determined from otoliths. Small bluegill (<50 mm) were identified as age-0 or age-1 fish by examining daily otolith rings. Daily rings were exposed by grinding the otolith to form a thin section in the sagittal plane; the spacing of daily rings was used to identify the first annulus. A minimum of five fish were aged from each 5 mm length interval, or all fish were aged if <5 were available. The remaining fish in the catch were assigned ages in proportion to the age composition of the subsample.

The size structure of age-0 bluegill was estimated from three shoreline rotenone samples spaced equally throughout the lake. A 4 mm mesh block net (30 m x 1.8 m deep) was deployed as described by Timmons et al. (1979) to enclose a rectangular area (0.02-0.07 hectares). Marked bluegill were added to estimate recovery rates. The water volume in the enclosure was estimated and enough rotenone (2-3 ppm) was applied with a hand sprayer to ensure a complete kill. Recovered fish were counted and a subsample was measured. Potassium permanganate was applied to detoxify the rotenone prior to removal of the barrier net.

Food habits of largemouth bass, walleye, and black crappie were collected monthly from April through November of each year. Methods similar to those previously described were used in these collections (see Jobs 3 and 4).

Findings:

Bluegill Population Structure: Individuals from the 1986 year class made up 94, 78, 54, 25, and 22% of the September 1987 through 1991 electrofishing samples, respectively. The high relative abundance of this year class indicates that a strong bluegill year class developed the first year that Ridge Lake was stocked (1986). These individuals were also abundant in the angler catch (Job 5).

Bluegill PSD increased from 6% in 1987 to 13% in 1988. This increase reflects growth of age-2 fish (in 1988) into the quality-size range (≥150 mm) because nearly all of the stock-size bluegill collected in 1987 and 1988 were individuals from the 1986 year class. In 1987 and 1988, PSD values were below the range of 20-40% suggested for bluegill in impoundments where fishing for largemouth bass and bluegill is important (Novinger & Legler 1978). Bluegill relative weight values were also below average (95-105%). Mean relative weights for small (100-149 mm, N = 54) and large bluegill (150-200 mm, N = 42) collected in 1988 were 87 and 83%, respectively. These low index values, which measured the size structure and condition of one dominant bluegill year class, are probably typical in new and renovated impoundments where the first year class of bluegill produced in the lake is numerically dominant.

Bluegill PSD increased to acceptable levels of 31, 24, and 42% in 1989, 1990, and 1991, respectively, indicating that bluegill population size structure may have stabilized after the initial dominance of the 1986 year class. Harvest of larger individuals from this year class by anglers and recruitment of the 1987 year class into the stock size range combined to reduce the relative abundance of the 1986 year class. As with bluegill PSD, mean relative weights for small bluegill increased over time to a high of 98% in 1991. In contrast, condition of large bluegill did not improve with time; mean relative weight for these larger fish were 80, 82, and 87% in 1989, 1990, and 1991, respectively.

In 1992, bluegill PSD declined sharply, from 46% to 5%. This marks the removal of the majority of the strong initial (1986) year class through angling and natural mortality. Mean relative weight for bluegill collected in 1992 also declined; mean Wr for small and large bluegill were 90% and 79%, respectively.

In comparison to the high density of largemouth bass in the lake (density = 96-225 age-1 and older fish/hectare), walleye (density <22 fish/hectare) probably had little impact on bluegill abundance and size structure in 1987-1992. It also appears that the introduction of gizzard shad might mediate the impact of walleye on the bluegill population because this alternative prey species replaced bluegill as the principal taxon found in the diets of walleye (see Study 102b).

<u>Predator Food Habits</u>: Bluegill were the principal taxa eaten by largemouth bass in Ridge Lake during 1987 through 1989 (Table 6). In these years, bluegill made up 64% of the volume of food in stomachs of largemouth bass <205 mm and 46% of the volume in all sizes of largemouth bass combined. Consumption of bluegill by largemouth bass decreased as crayfish became a more important part of the diet of bass >205 mm in length. After gizzard shad were introduced to Ridge Lake in 1989, they became an important part of the diets of largemouth bass. This species made up 37% of the food volume of largemouth bass stomachs sampled in 1990-92. Gizzard shad were most important to intermediate-size largemouth bass (205-343 mm). Year-to-year variation in contribution of food items to largemouth bass diet was apparent, possibly due to changes in size structure and availability of prey items. Gizzard shad were more important for small (140-204 mm) bass in 1990, but not for larger (>343 mm) fish. Conversely, in 1992 shad were important for large bass, but did not occur in small bass stomachs. Differences in the size structure of the gizzard shad population between 1990 and 1992 may, in part, explain the differences in use of shad by bass. Bluegill and crayfish continued as a major component of largemouth bass diets, even after gizzard shad were introduced to Ridge Lake.

Temporal trends in the food habits of largemouth bass were similar in all years. Fish, mostly bluegill and gizzard shad (1990-1991), were important in the bass diets during all months; however, fish occurred most frequently and constituted the highest percent volume during September and October. Crayfish occurred most frequently during mid-summer (June and July), but made up a high percentage (>25%) of the food volume in all months. Insects were eaten primarily in the spring.

In contrast to largemouth bass, walleye fed almost exclusively on fish (see Job 3). The potential for interspecific competition exists in Ridge Lake because bluegill was a principal component in the diets of both species. However, the increase in percent volume and frequency of occurrence of bluegill in largemouth bass diets from 1987 through 1989, years when walleye were present in the lake, indicates walleye were not impacting largemouth bass food habits. Because largemouth bass density in Ridge Lake is extremely high relative to walleye density, intraspecific competition for food, rather than interspecific competition, is more likely to be important in determining diet and growth of largemouth bass.

Insects and small fish, primarily Chaoborus sp. and bluegill, were the principal food items eaten by black crappie in 1988 and 1989. These taxa made up 90% of the volume and occurred in >95% of the crappie stomachs containing food. As with other predators in the lake, black crappie diets reflected the presence of gizzard shad in 1990. Gizzard shad made up 65% of the volume of the diet and occurred in 21% of the stomachs with food. In 1991 and 1992, gizzard shad still occurred in 18% and 11% of stomachs, but only made up 10% and 3% of food volume, respectively. Bluegill occurred in 21% and 11% of stomachs and accounted for 53% and 4% of food volume in 1991 and 1992, respectively.

Study Summary and Recommendations: We found large walleye fingerlings to have higher survival than smaller fingerlings or fry and that thermal stress at stocking and predation by largemouth bass were more important than hooking mortality or spillway escapement in determining walleye survival. By stocking walleye at least as large a 200 mm in the fall when lake temperatures have declined, we were able to reduce losses to largemouth bass predation and to thermal stress. Although initial costs are substantially higher for these large fingerlings compared with small fingerlings or fry, return on investment increased with walleye size and 200-mm fingerlings were the most economical walleye to stock. Unfortunately, growth of stocked walleye in small impoundments with centrarchid forage will be slower than that of walleye in lakes with other prey populations. Walleye did not appear to influence largemouth bass diets, and because of their relatively low density in Ridge Lake (<22 fish/hectare), walleye probably had little impact on centrarchid abundance and size structure. Because largemouth bass density in Ridge Lake is extremely high relative to walleye density, intraspecific competition for food, rather than interspecific competition, is more likely to be important in determining diet and growth of largemouth bass. Additional studies are needed across a wider range of systems to further evaluate the relative importance of forage base and predators in determining survival of various sizes of stocked walleye.

For channel catfish, we found that predation and other sources of mortality, as well as angler catch and angler harvest, were similar between 200-mm and 250-mm fish. In addition, return on investment was similar for both size groups. Because 250-mm fish did not have a higher economic return or contribute substantially more to the fishery than the smaller size group, stocking fingerlings larger than 200 mm appears unnecessary for most put-grow-and-take fisheries. However, rearing and stocking larger fish may be beneficial in lakes with an abundance of large predators or where channel catfish growth is slow. Additional efforts to manage channel catfish in small impoundments should focus on optimizing yield by regulating angler exploitation. High exploitation rates and low hooking mortality of all sizes of fish suggest that protective size limits may be useful in deferring fishing mortality, thus increasing the size of fish available for harvest without substantially reducing numerical harvest. Further studies are needed to determine the specific effects of harvest restrictions on stocked channel catfish populations.

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Table 6. Percent composition of food items by volume of the diet for various size classes of largemouth bass collected by electrofishing and angling at Ridge Lake, 1987-1992. Gizzard shad were not present in the lake before 1990.

Year	Food items					
	Insects	Crayfish	Bluegill	Gizzard shad	Other fish	Other
			140-204 mm			
1987	23	23	38	--	14	2
1988	17	5	58	--	16	3
1989	19	1	69	--	6	4
1990	19	1	13	77	<1	1
1991	4	1	40	22	30	3
1992	0	0	81	0	19	0
			205-293 mm			
1987	11	33	36	--	14	6
1988	8	40	39	--	9	5
1989	18	22	49	--	4	7
1990	8	8	23	55	1	4
1991	2	11	12	46	16	13
1992	2	9	54	15	9	12
			294-343 mm			
1987	10	51	31	--	6	1
1988	2	51	26	--	15	5
1989	6	46	24	--	12	11
1990	1	29	6	40	0	25
1991	<1	14	20	50	5	10
1992	<1	9	13	58	13	6
			>343 mm			
1987	4	74	10	--	4	8
1988	1	46	35	--	10	9
1989	1	27	49	--	15	8
1990	2	31	68	0	0	0
1991	0	1	0	26	72	1
1992	<1	0	32	53	15	<1

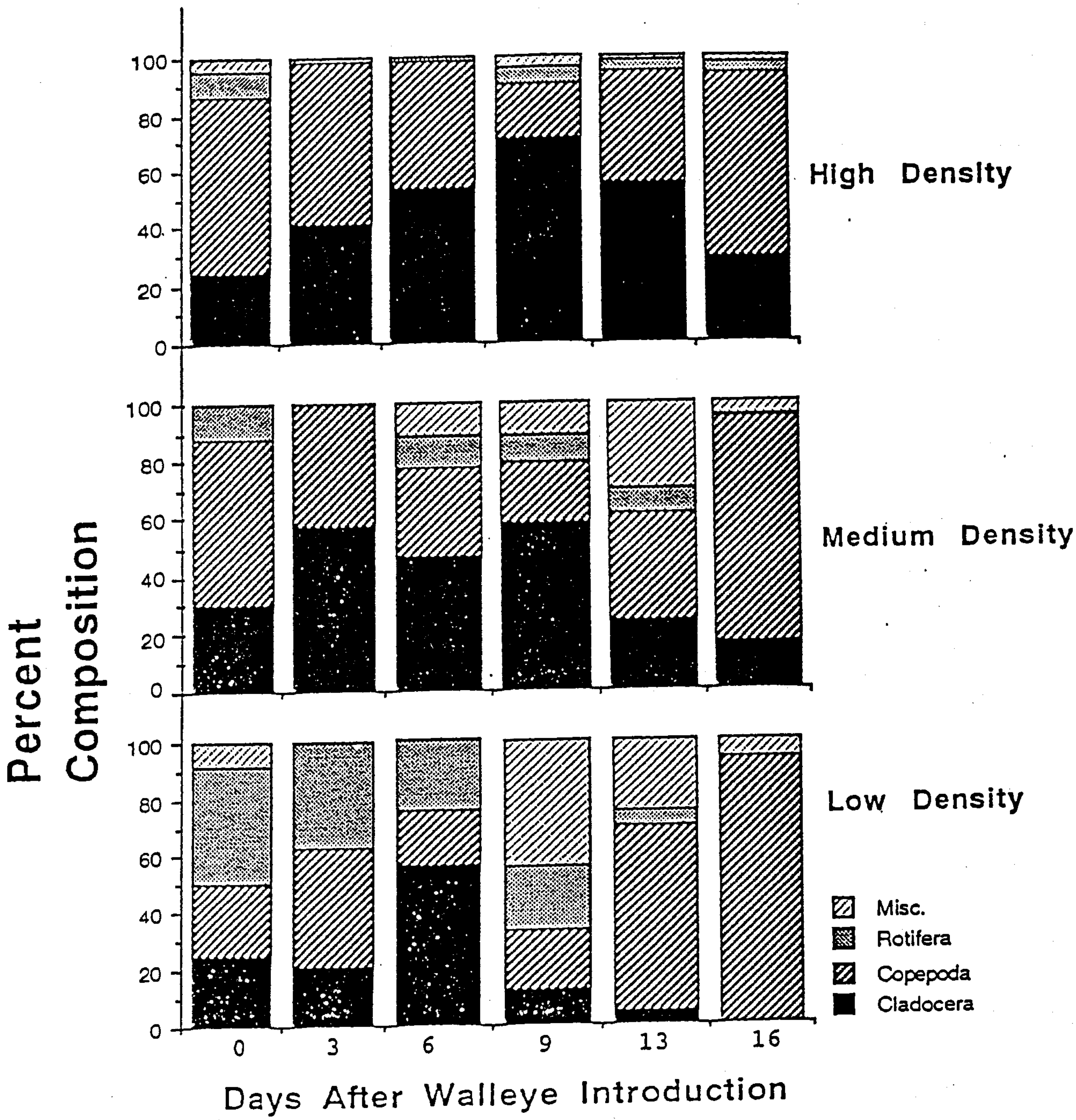

Figure 2. Composition of the zooplankton populations by taxonomic order throughout 16-day experiment in tanks with low, medium, and high initial densities of zooplankton.

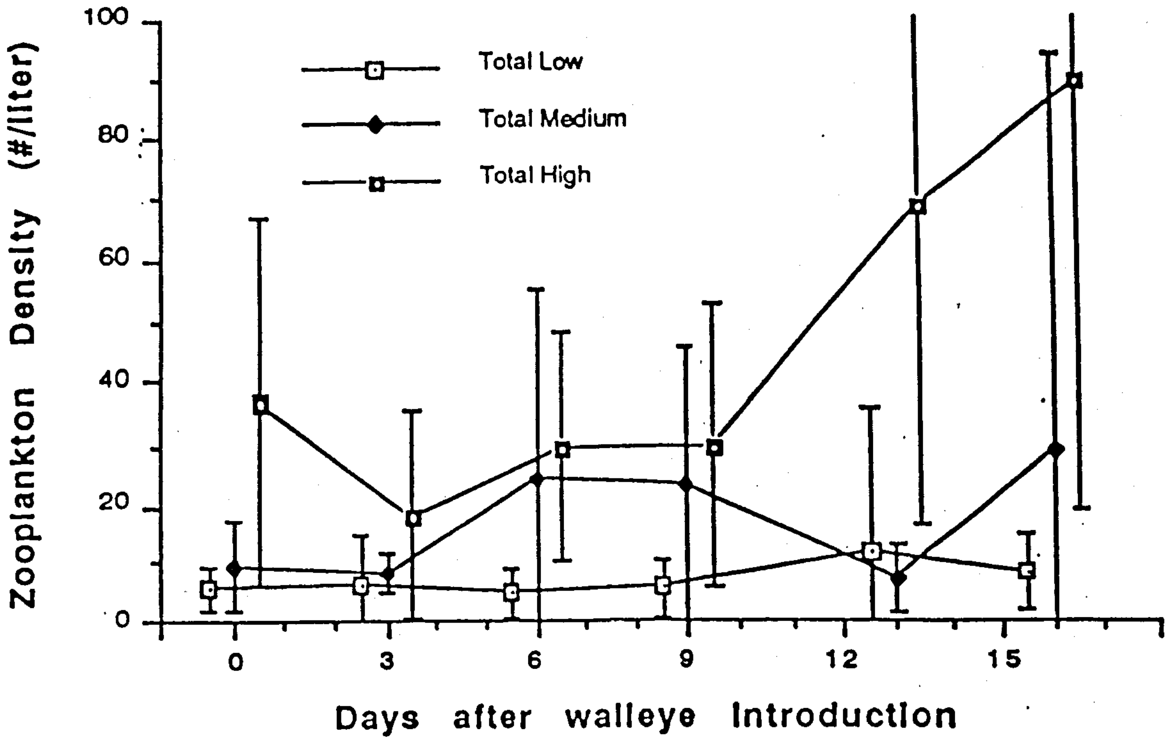

Figure 3. Average zooplankton density with 95% confidence intervals throughout 16-day experiment in tanks initially stocked with low, medium, or high numbers of zooplankton (N = 4 for each treatment).

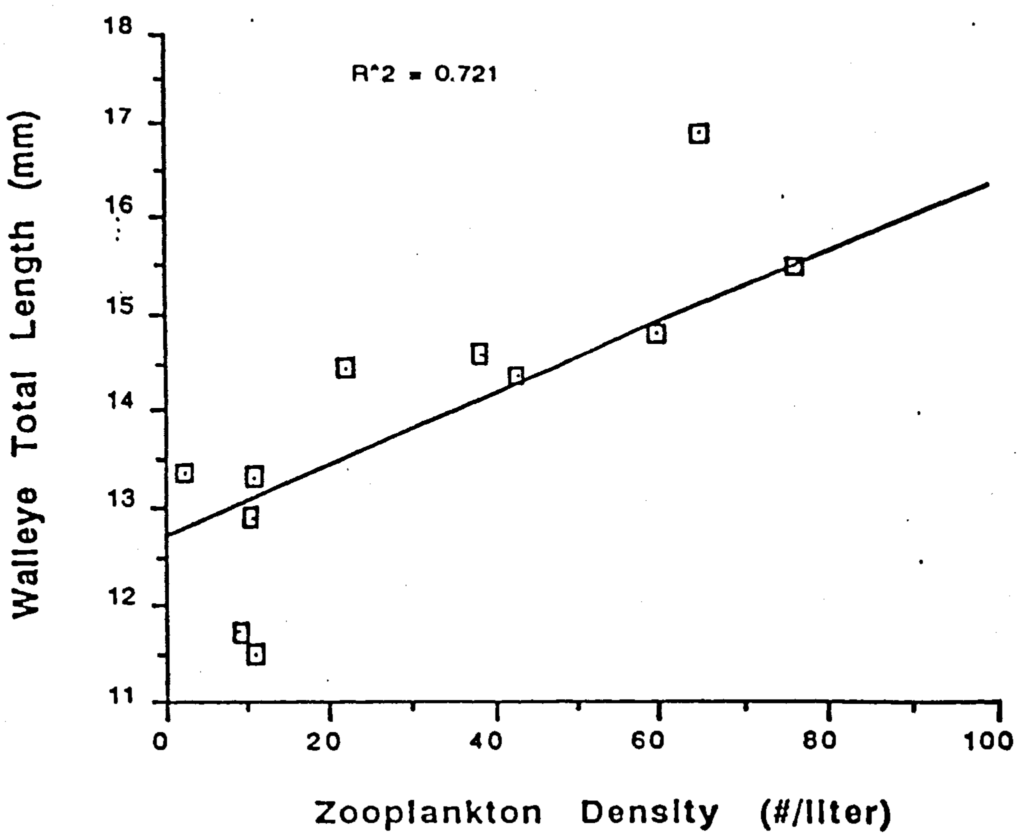

Figure 4. Walleye growth (total length, mm) after 16-days in tanks with varying zooplankton densities.

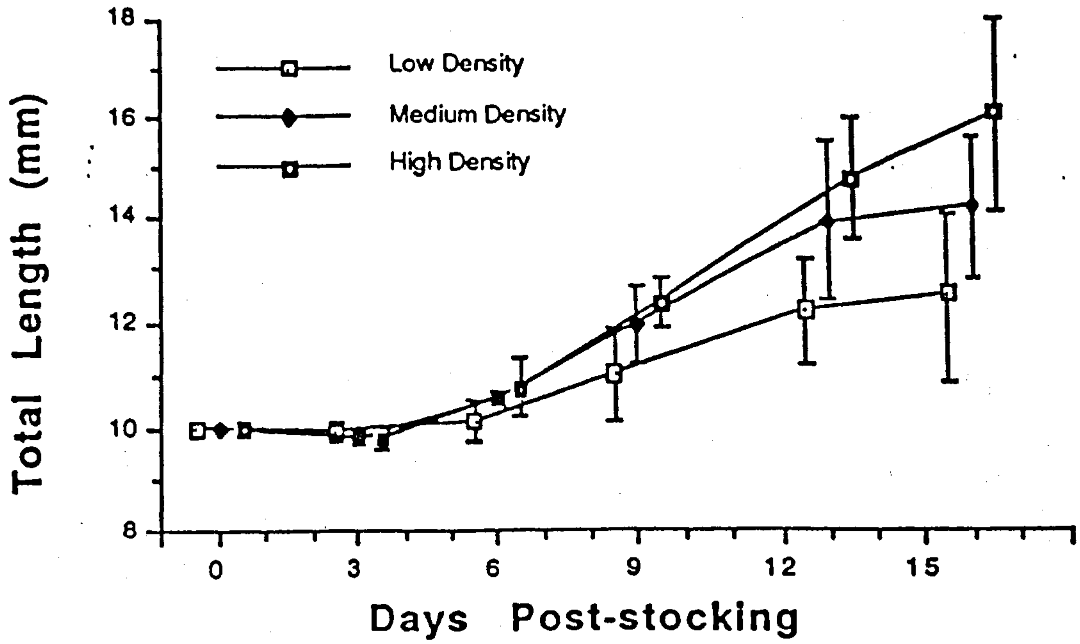

Figure 5. Mean total lengths with 95% confidence intervals for walleye in tanks containing either a low, medium, or high density of zooplankton (N = 4 for each treatment).

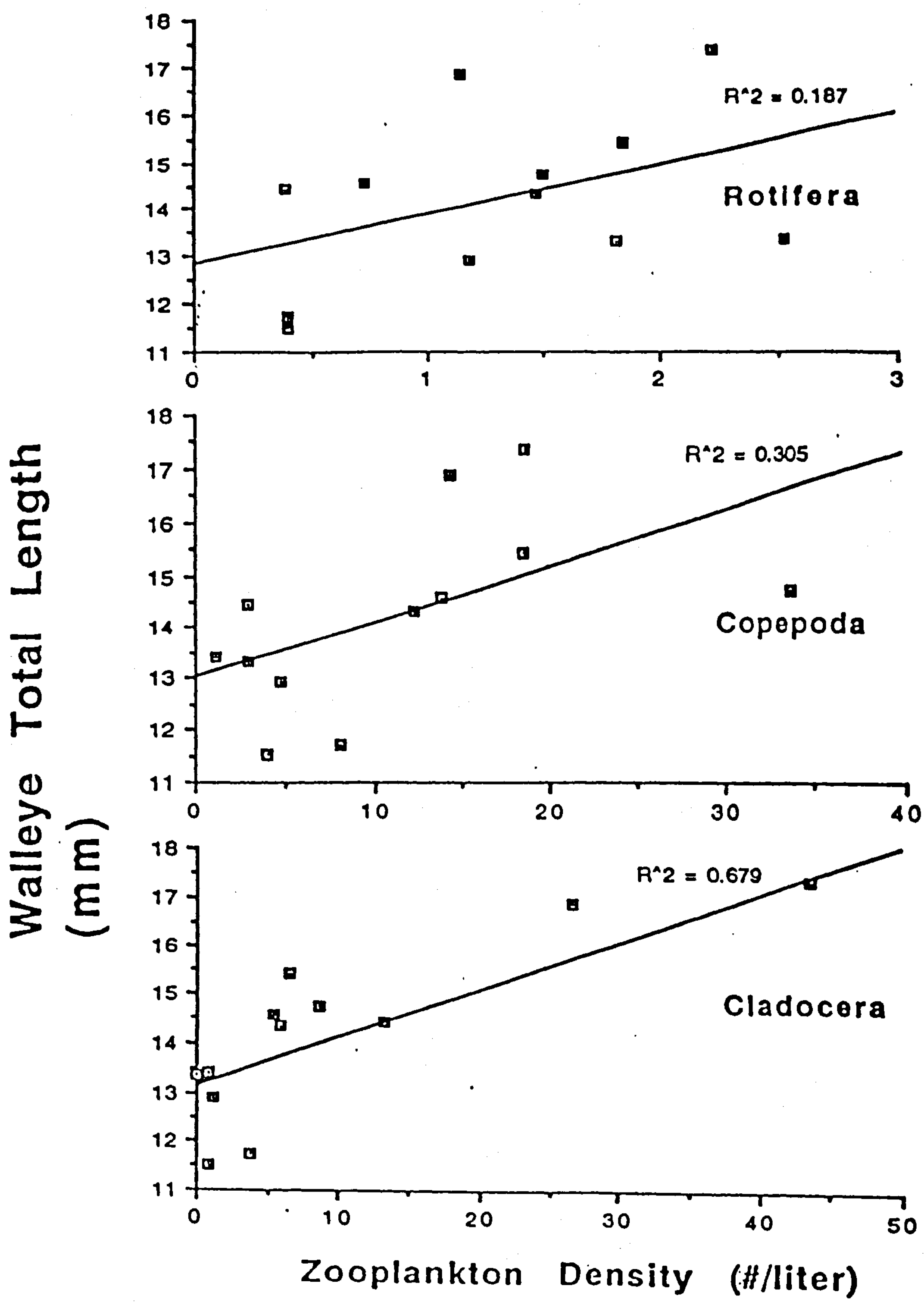

Figure 6. Relationship of walleye growth to average density of three taxonomic Orders of zooplankton after two weeks in tank experiments.

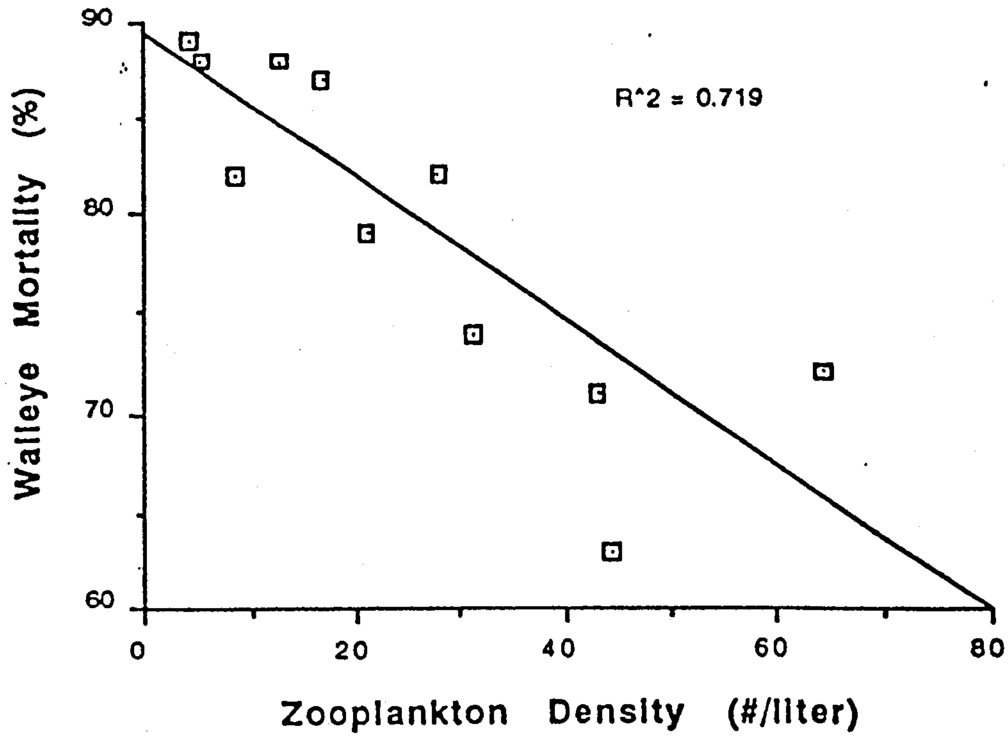

Figure 7. Walleye mortality after two-weeks in tanks with varying zooplankton densities.

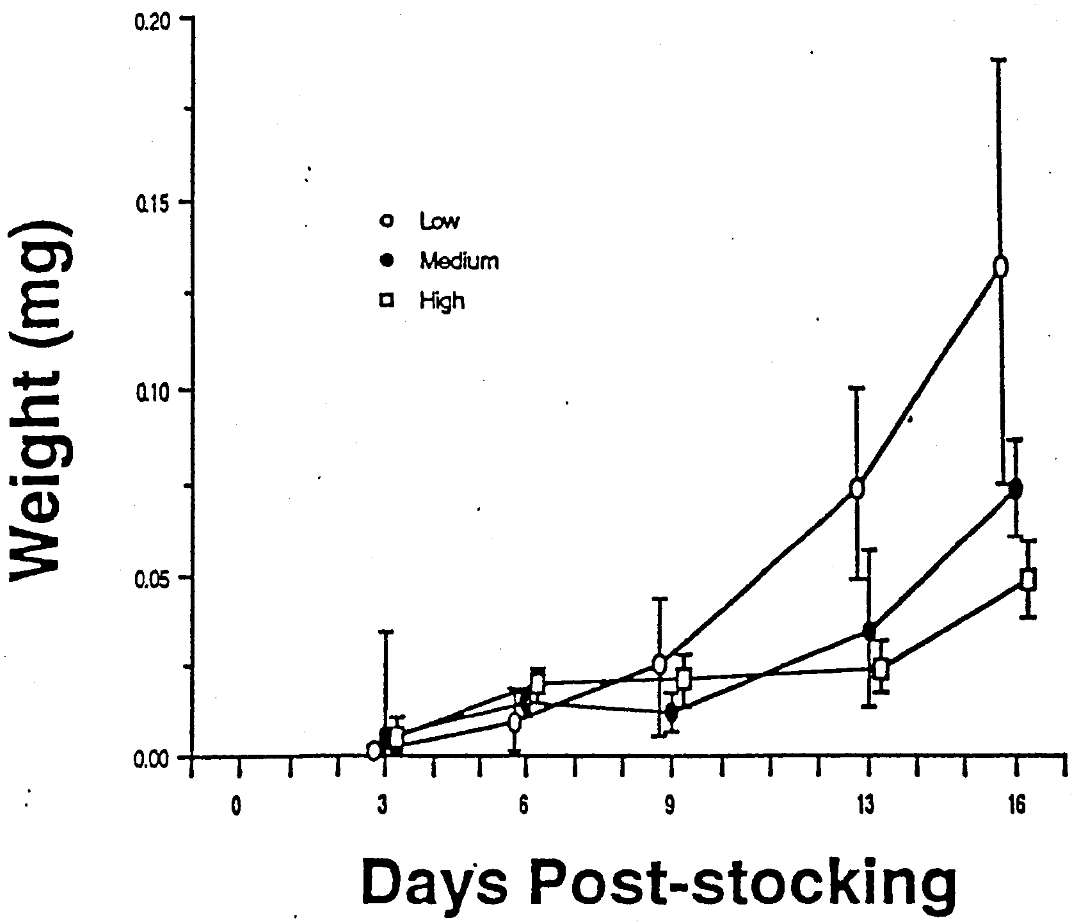

Figure 8. Average dry weight of food items in the stomachs of walleye fry collected from tanks with low, medium, and high densities of zooplankton. Vertical lines represent 95% confidence intervals.

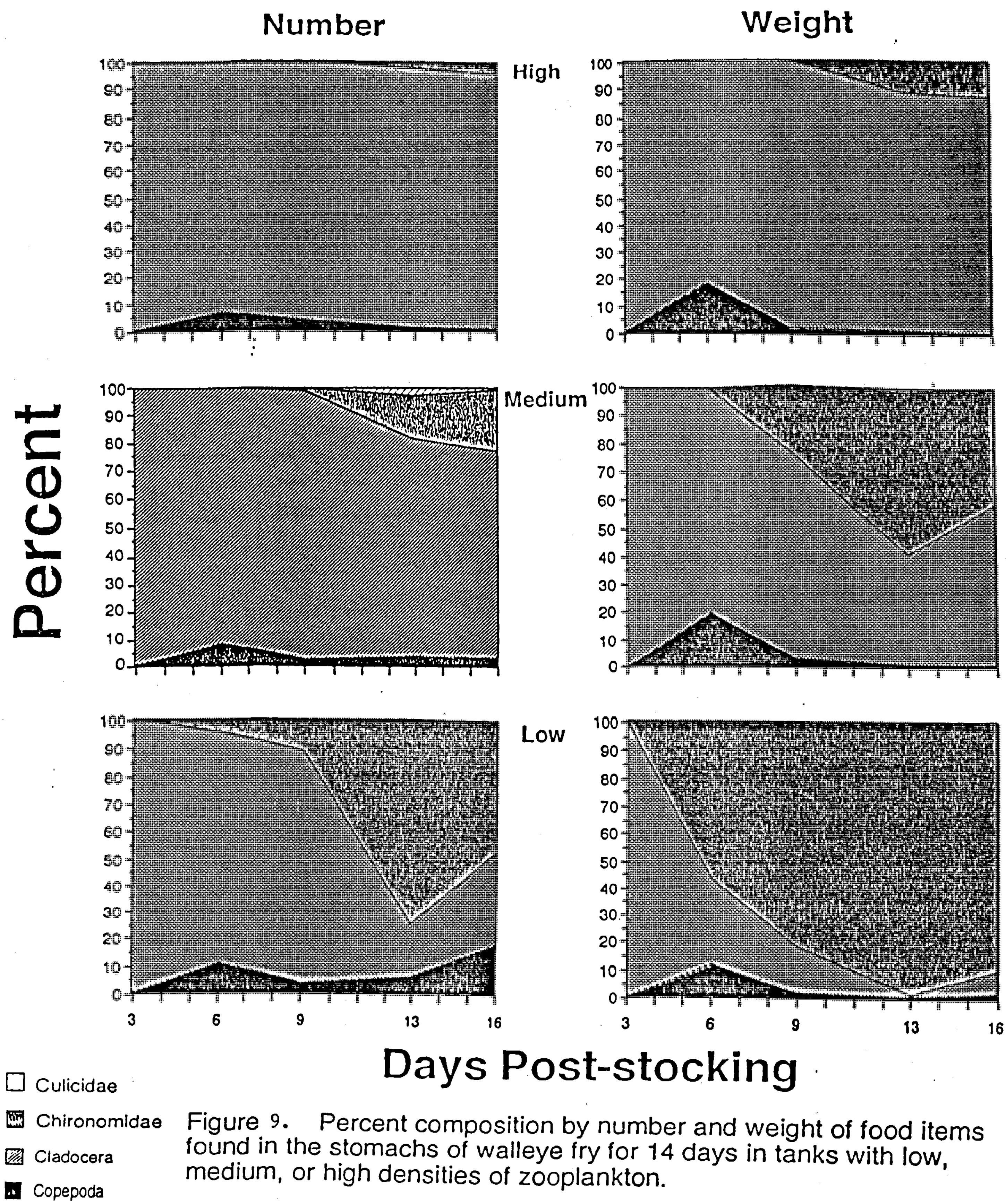

Figure 9. Percent composition by number and weight of food items found in the stomachs of walleye fry for 14 days in tanks with low, medium, or high densities of zooplankton.

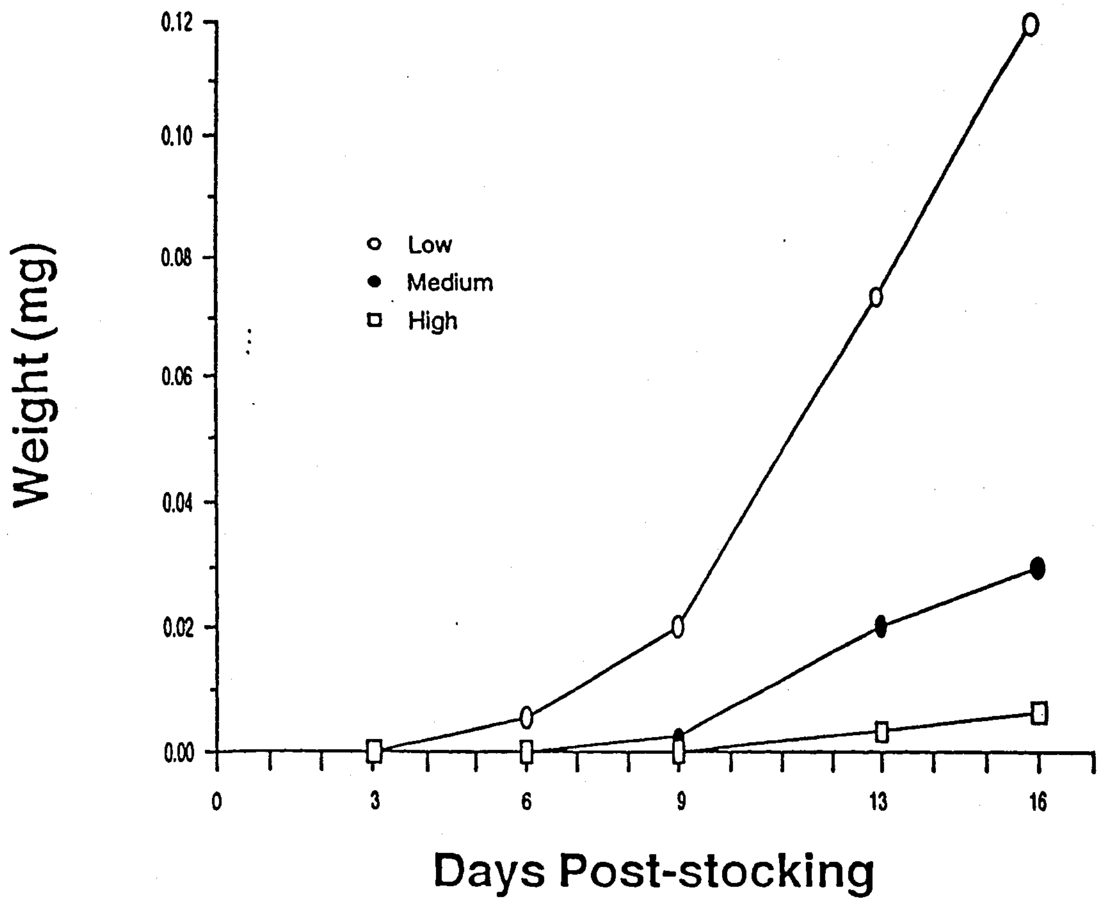

Figure 10. Average dry weight of chironomids consumed by walleye fry from tanks with low, medium, and high densities of zooplankton.

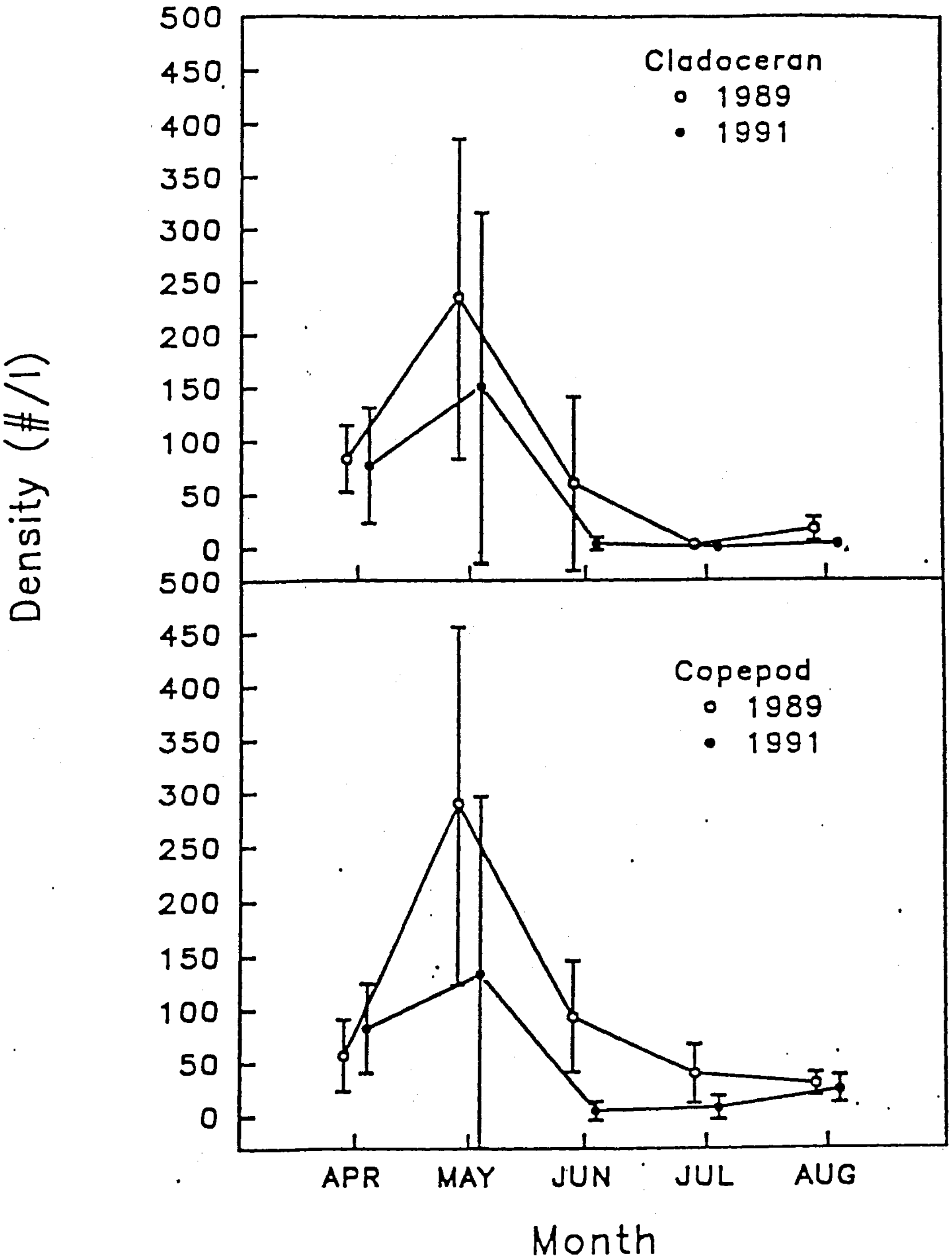

Figure 11. Cladoceran and copepod zooplankton density in Ridge Lake, Illinois, 1989 and 1991.

Study 102b. Effect of the introduction of gizzard shad on walleye and centrarchid fish populations.

Objective: To determine the impact of the introduction of gizzard shad on resident centrarchid populations and stocked walleye in a small impoundment, and to make management recommendations regarding manipulation of forage and game fish populations.

Job 102.1. Survival of walleye and centrarchid predators.

Objective: To compare size-specific survival of walleye and centrarchid predators before and after introduction of gizzard shad into a small impoundment.

Introduction: Angling demand for game fish often exceeds the supply available for harvest in centrarchid-dominated, warm-water impoundments. In addition, the surplus production of panfish populations, particularly bluegill, is often not fully utilized by piscivorous species in these systems. Two solutions to these management problems are the stocking of an additional predator species and the introduction of alternate forage species. Forage fish introductions have been used for some time in attempts to improve sport fish, in particular largemouth bass populations (Noble 1981, DeVries and Stein 1990). Clupeid introductions have tended to enhance predator populations (DeVries and Stein 1990), but results have been inconsistent, and the mechanisms underlying these impacts are not well understood. The introduction of gizzard shad into Ridge Lake gave us the opportunity to examine the potential for forage fish manipulation to influence fish populations in the lake, in particular to examine the effects of the introduction of gizzard shad on survival and recruitment of stocked walleye and resident centrarchids in a small impoundment with a forage base previously dominated by bluegill.

The potential for supplementally stocked walleye and resident centrarchids to contribute to the sport fishery of warm-water impoundments depends substantially on early survival and growth rates of these fish. Introduction of gizzard shad may improve largemouth bass growth rates because they are easier to catch and digest than other prey items, such as bluegill (Wahl and Stein 1988). Walleye recruitment has been linked to early growth, over-winter survival, and food availability (Mandenjian et al. 1991, Schneider 1979). Previous work in Ridge Lake evaluated survival of four sizes of stocked walleye (Santucci and Wahl 1993). Survival during the first year after stocking was relatively low, but higher for 8.5-inch walleye than for either 2.5- or 5.5-inch fish. Survival to 24 months following stocking was variable, but some evidence suggests that gizzard shad or other similar forage may lead to increased survival (Clapp and Wahl 1992). For fry and 2.5-inch walleye stockings, timing relative to gizzard shad spawning may be important in determining ultimate survival, whereas growth rates and behavioral differences (Tisa and Ney 1991) may be more important for larger fish stocked later in the year.

Largemouth bass predation can at times be an important source of explained mortality for stocked walleye. Alternate prey in the form of gizzard shad may lead to decreases in predation on stocked walleye (Forney 1976), as well as on young-of-year (YOY) centrarchids. In the current study, we estimated losses of all size groups of stocked walleye to largemouth bass predation, as well as losses of YOY largemouth bass and black crappie to predators, and examined how this mortality changed with the introduction of gizzard shad.

Procedures: Walleye fry and fingerlings were stocked in Ridge Lake during spring, summer and fall of each year. Size groups were distinguished by fin clips, except for fry which were unmarked. Walleye fry were stocked at a rate of 2,471/hectare. Fingerlings were stocked at three sizes, small (2.5 inch, 124/hectare), medium (5.5 inch, 62/hectare) and large (8.5 inch, 25/hectare). The role of stocking stress in determining survival of all sizes of walleye was assessed by holding a sub-sample in floating cages for 48 h following stocking. Following each of the lake stockings we determined losses of walleye to largemouth bass. Largemouth bass were collected by electrofishing and from the angler creel. Numbers of walleye in bass stomachs were combined with largemouth bass population estimates to determine the total number of stocked fish lost to predation. Losses of YOY largemouth bass and black crappie to largemouth bass, black crappie, and walleye predators were evaluated using bi-weekly diet samples collected between April and November in 1987-1994. Losses of stocked walleye and resident centrarchids to predation after introduction of gizzard shad were compared to those observed during previous segments of the project.

Additionally, survival of all four size classes of stocked walleye, as well as survival and/or year class strength of resident centrarchids (largemouth bass, bluegill, black crappie), was assessed using fall population estimates and electrofishing catch per unit effort (CPUE). Fish for fall population estimates were collected by electrofishing the perimeter of the lake. Schnabel population estimates were made using recapture data from successive sampling dates. Survival and/or year class strength of walleye, largemouth bass, bluegill and black crappie were compared before and after introduction of gizzard shad.

Findings: Results of work conducted in this job are reported in Appendix C, Clapp and Wahl. Effect of gizzard shad on centrarchid and percid populations. To be submitted to Transactions of the American Fisheries Society.

Job 102.2. Growth and food habits of walleye and centrarchid predators.

Objective: To compare size-specific growth and food habits of walleye and centrarchid predators before and after introduction of gizzard shad into a small impoundment.

Introduction: The effects of the introduction of gizzard shad into a lake are likely to be complex (DeVries and Stein 1992). Gizzard shad may improve growth rates of resident and stocked predators. However, by competing for zooplankton, gizzard shad may also negatively affect growth and recruitment of these same predators, as well as reduce growth and recruitment of other prey species, such as bluegill. Few studies have adequately addressed these potential interactions because they are complex and affect many trophic levels. Because of the extensive sampling conducted in Ridge Lake in previous studies, we had the opportunity to evaluate the effect of gizzard shad introduction on the predator and forage fish communities in a small impoundment. Information concerning predator-prey relationships in small impoundments will help determine the likelihood for success of forage fish introductions in these waters.

An obvious impact of the introduction of forage fish would be major shifts in the diets of predator species. Based on data collected in earlier segments of this study, after gizzard shad were introduced to Ridge Lake, they became an important part of the diets of adult walleye and largemouth bass. Use of shad may vary with predator size, and with time of year. Timing of gizzard shad spawning and growth rates of shad have the potential to significantly impact their use by walleye and centrarchid predators. In addition, the use of specific prey by walleye will influence potential competition with largemouth bass and ultimately determine effects of these predators on bluegill populations.

By causing changes in diet, introduction of alternative forage species can ultimately alter growth patterns. Beyerle (1978) and Schneider (1975, 1979) found that walleye grew more slowly with bluegill than when minnow forage were available. Based on previous work, we would expect to see increased growth rates of walleye in Ridge Lake after introduction of gizzard shad. Prior to this study, evaluations of the impact of gizzard shad introductions on growth of centrarchid and percid predators had not been completed. We examined growth of walleye and centrarchid predators before and after the introduction of gizzard shad in a small impoundment with a predominantly bluegill forage base.

Gizzard shad populations may influence not just predator species, but other forage species as well. Gizzard shad may compete directly for food, or may indirectly increase recruitment of other forage species by causing decreases in predation pressure on those species. Increased recruitment of bluegill may have negative consequences, such as stunting. The introduction of gizzard shad in Ridge Lake gave us the opportunity to evaluate competitive interactions between gizzard shad and centrarchid forage, such as bluegill.

Procedures and Findings: Results of work conducted in this job are reported in Appendix C, Clapp and Wahl. Effect of gizzard shad on centrarchid and percid populations. To be submitted to Transactions of the American Fisheries Society.

Job 102.3 Gizzard shad competition with larval fishes.

Objective: To examine competitive relationships between larval gizzard shad, bluegill, largemouth bass, and walleye, as influenced by zooplankton populations.

Introduction: Introduction of gizzard shad to an impoundment may result in competition among larval fish and possible resource depletion (Dettmers and Stein 1992). This competitive effect may influence all fish species in an impoundment. Results of investigations into the complex relationships between piscivores, planktivores, and zooplankton in small impoundments have been mixed (DeVries et al. 1991). Temporal and spatial availability of zooplankton can have profound effects on growth of juvenile fish and subsequent recruitment (Miller et al. 1990). Zooplankton abundance can directly affect sport fish growth and survival in early life history stages, and indirectly by influencing growth and survival of their prey (DeVries et al. 1991). Competitive influences may be particularly intense on bluegill populations, since, like gizzard shad, they depend on zooplankton during the majority of their larval and juvenile life history. Gizzard shad generally spawn earlier in the year than bluegill and because they are so prolific, have the potential to severely limit zooplankton resources for bluegill. If, however, gizzard shad are introduced into a lake with abundant (i.e., non-limiting) zooplankton resources, shad and bluegill populations may co-exist, to the advantage of predator populations. Likewise, if zooplankton populations rebound following depletion by gizzard shad, larval bluegill may not be severely impacted. By monitoring the timing of gizzard shad and bluegill spawning, as well as larval fish density and growth in relation to zooplankton density and species composition, we hoped to gain a better understanding of these relationships. Data collected allowed us to make comparisons concerning the year-to-year variation in forage availability and growth and how this variation influenced walleye and centrarchid survival and growth.

Larval gizzard shad may serve as forage for young-of-year largemouth bass, and the presence of this additional forage may lead to increased growth rates and thus increased over-winter survival for these young bass (Adams et al. 1982). However, larval gizzard shad may also have a negative influence on largemouth bass populations by competing with larval bass (DeVries and Stein 1990, DeVries et al. 1991). The extent to which each of these processes occurs will depend on the abundance of larval fish, zooplankton, largemouth bass and alternative forage. Additional information will help us in explaining these relationships.

Gizzard shad introductions may also influence the success of walleye fry stockings in small impoundments. Gizzard shad may have positive (by providing larval prey) or negative (by competing for zooplankton resources) effects on walleye fry. Examination of zooplankton samples from Ridge Lake prior to introduction of gizzard shad indicated that zooplankton is abundant during the time of walleye fry stocking. While density of large zooplankters remained at a level (greater than 50 organisms/l) that, based on laboratory experiments, should have ensured the highest survival and best growth of stocked walleye fry, survival appeared to be low. In the current job we evaluated how the introduction of gizzard shad influences zooplankton density and species composition and in turn, the effect of these influences on success of walleye fry stocking.

Procedures and Findings: Results of work conducted in this job are reported in Appendix C, Clapp and Wahl. Effect of gizzard shad on centrarchid and percid populations. To be submitted to Transactions of the American Fisheries Society.

Job 102.4. Catch and harvest of sport fish in a small impoundment.

Objective: To determine the impact of a gizzard shad introduction on catch and harvest of five sport-fish species in a small impoundment.

Introduction: In order to be a successful management tool for small impoundments, the introduction of alternate forage must lead to increases in survival and growth, as well as catch and harvest, of resident predator species, including largemouth bass, stocked walleye and channel catfish. Fish from the earliest walleye and catfish stockings at Ridge Lake began to reach harvestable and quality (Anderson and Gutreuter 1983) sizes in 1993. The addition of gizzard shad to Ridge Lake could lead to changes in catch and harvest rates and improvement in the number of fish reaching quality size. In addition, an alternate or additional forage item may lead to increases in the weight of fish caught and harvested.

Size limits (356 mm) for channel catfish may also lead to increases in the size of fish in the catch. Harvest regulations may also be useful for maximizing benefit/cost relationships for walleye and channel catfish stockings. By protecting fish for a longer period of time, catch rates and benefits from each stocking may be increased. Objectives of this job were to evaluate the influence of the introduction of gizzard shad on catch and harvest of five sport fish species in Ridge Lake, and to evaluate the utility of size limits for maximizing catch and harvest (in weight) of channel catfish.

Procedures: Equal numbers (N = 375) of 8- and 10-inch channel catfish were stocked in Ridge Lake in 1986-1994 as they became available from the hatchery. Size groups were distinguished using pelvic fin clips, and year classes were identified using adipose clips. Walleye (four size groups) were stocked as described in Job 102.1.

We used data collected from a complete creel census to evaluate catch, harvest, growth, and relative survival of walleye, channel catfish, largemouth bass, bluegill, and black crappie. Survival of these species was also determined using fall population estimates. Catch data was combined with estimates of population sizes to assess angling vulnerability and to assess whether vulnerability and harvest varied due to the presence of an alternate forage such as gizzard shad. Data collected will be compared to data on catch and harvest prior to the introduction of gizzard shad.

Minimum length limits of 356 mm were in effect since 1990 for channel catfish. Harvest regulations may be useful for maximizing benefit/cost relationships for stocked channel catfish. Catch and harvest data from before and after the implementation of the minimum length limits were compared to evaluate the utility of size limits for maximizing catch and harvest (in weight) of channel catfish in small impoundments, as well as benefit/cost relationships described.

Findings: Results of work conducted in this job are reported in Appendix C, Clapp and Wahl. Effect of gizzard shad on centrarchid and percid populations. To be submitted to Transactions of the American Fisheries Society.

Size limits (356 mm) for channel catfish may lead to increases in the size of fish in the catch, and may also be useful for maximizing benefit/cost relationships for channel catfish stockings. By protecting fish for a longer period of time, catch rates and benefits from each stocking may be increased. A preliminary evaluation of the effects of regulations on the channel catfish fishery indicates that maximum harvest of catfish in a small impoundment may be close to 75-80% for 10-inch catfish, but only about 55-60% for 8-inch fish (Figure 12; 1986-1989). However, a 356-mm minimum length regulation has the potential to extend the time period over which this harvest occurs (Figure 12; 1990-1994), and possibly increase the total biomass of catfish harvested. Prior to the implementation of this regulation at Ridge Lake, 52% of 8-inch catfish and 69% of 10-inch catfish were harvested 3 years following stocking. After implementation of the regulation, harvest for these two groups 3 years following stocking was 15% and 25%, respectively.

Study Summary and Recommendations:

In Study 102b, begun in 1993, we sought to determine the impact of the introduction of gizzard shad on resident centrarchid populations and stocked walleye in a small impoundment, and to make management recommendations regarding manipulation of forage and game fish populations. Gizzard shad introduction appeared to have had a substantial negative impact on centrarchid survival, possibly through competition for food or interference with spawning activities. In contrast, gizzard shad had little influence on overall walleye survival, but may have influenced predation mortality. Density of forage fish other than gizzard shad (i.e., centrarchids) had more of an influence on walleye survival. Additionally, gizzard shad introduction led to major shifts in diet of walleye and to slight improvements in growth. Growth of centrarchid species did not appear to be affected positively or negatively.

Gizzard shad had no observable positive impact on catch, harvest, and growth of primary sport fish species in Ridge Lake, but may have negatively influenced largemouth bass catch. In general, the effects of introducing gizzard shad may be positive or negative, depending on the target species and population attribute of interest. With this in mind, introduction of gizzard shad to improve sport fish populations should be undertaken only with caution and after careful consideration of management objectives.

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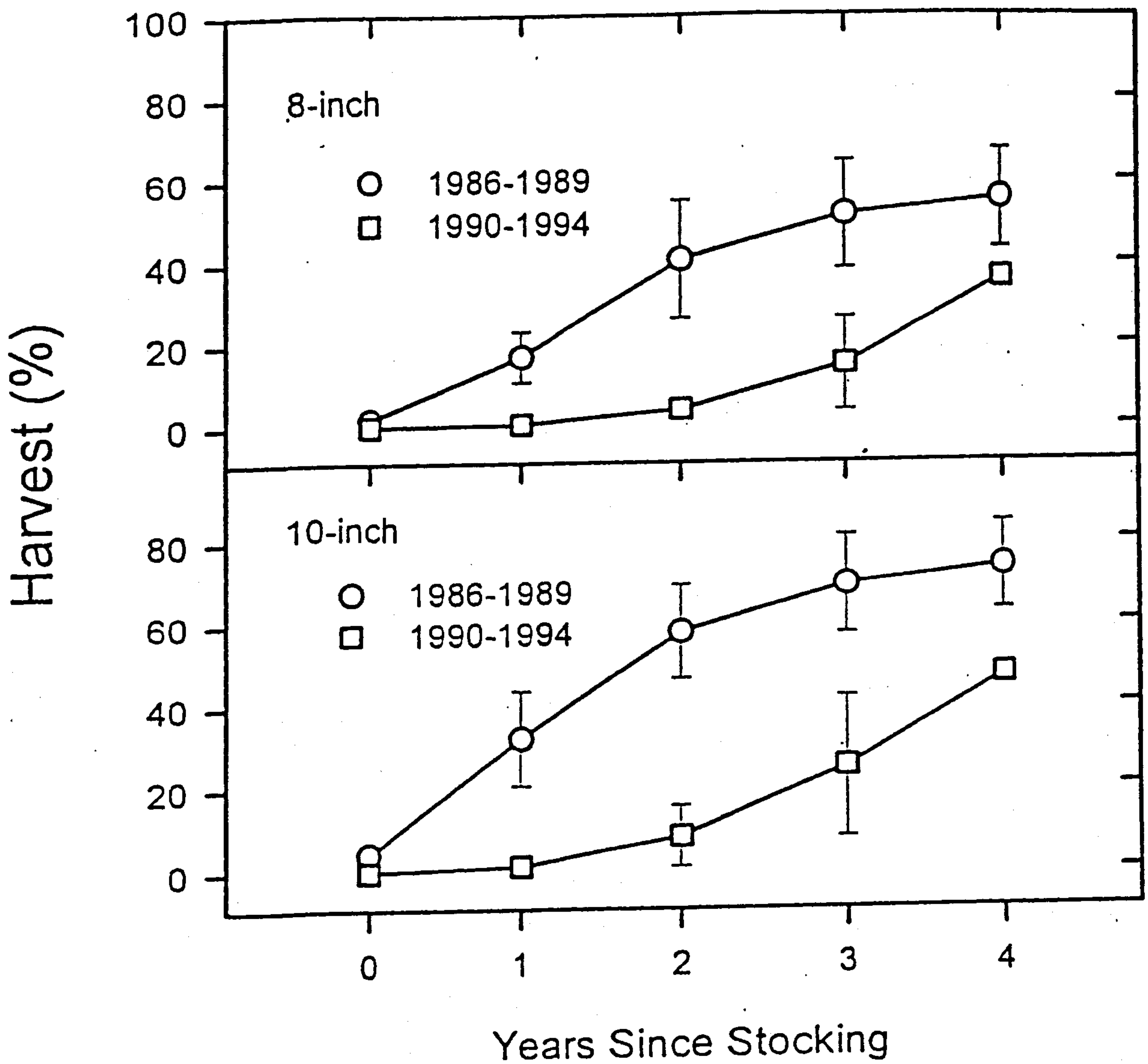

Figure 12. Cumulative harvest of two size-classes of channel catfish stocked in Ridge Lake, Illinois, 1986-1994. A 356-mm minimum length limit was instituted for channel catfish at Ridge Lake in 1990. Values are average cumulative percent harvest for all years. Data were obtained from a creel census.

APPENDIX A

Factors influencing survival and growth of stocked walleyes in a centrarchid-dominated impoundment

Victor J. Santucci, Jr.[1]

Ridge Lake Station, Illinois Natural History Survey,

R. R. 1, Box 233, Charleston, Illinois 61920, USA

David H. Wahl

Center for Aquatic Ecology, Illinois Natural History Survey and

Department of Ecology, Ethology, and Evolution, University of Illinois,

607 E. Peabody Drive, Champaign, Illinois 61820, USA

[1] Present address: Max McGraw Wildlife Foundation, Post Office Box 9, Dundee, Illinois 60118, USA.

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Abstract

We compared survival and growth of fry and small (mean total length = 48-61 mm), medium (132-145 mm), and large (186-216 mm) fingerling walleyes (Stizostedion vitreum) stocked for 4 yr in a centrarchid-dominated impoundment. Mean survival based on fall population estimates 1 and 2 yr after stocking indicated highest survival for large fingerlings (mean survival = 31 and 10%, respectively), followed by medium ones (7 and 4%). Few individuals from the fry and small fingerling size groups were recovered in extensive field sampling. Creel census data reinforced these findings. Thermal stress at stocking and predation by largemouth bass (Micropterus salmoides) were more important than either hooking mortality or spillway escapement in influencing survival. Walleye diets were dominated by bluegills (Lepomis macrochirus) in volume (87%) and frequency of occurrence (84%). Growth rates were slower with bluegills as predominant prey compared to walleye growth in waters containing clupeids and cyprinids, and may have been influenced by the abundance and size distribution of bluegills. Based on benefit/cost analysis (survival or catch/cost of rearing) stocking walleyes >200 mm provided the highest return on investment.

Introduction

Stocking of walleyes (Stizostedion vitreum) is often required to maintain populations because of overexploitation (Anthony and Jorgensen 1977; Schupp and Macins 1977) or because successful reproduction is precluded by factors such as inadequate spawning substrate (Johnson 1961; Ney 1978; Prentice and Clark 1978), inappropriate water temperatures in winter (Hokanson 1977) or at spawning time (Prentice and Clark 1978), and egg predation (Wolfert et al. 1975). The potential for walleyes to contribute to a sport fishery depends on the survival and growth of stocked fish. Survival and growth of various sizes of stocked fry and fingerling walleyes have been estimated frequently (Laarman 1978), but not in small centrarchid-dominated impoundments. Because small impoundments are an important and often heavily utilized resource (Anderson 1976), managers are interested in either providing additional sport species or maintaining existing populations in these systems.

To be successful in waters dominated by centrarchids, stocked walleyes must avoid predators such as largemouth bass (Micropterus salmoides) and consume prey such as bluegills (Lepomis macrochirus). Whereas largemouth bass predation is an important cause of mortality of other stocked species (Krummrich and Heidinger 1973; Stein et al. 1981; Wahl and Stein 1989), predation has not been evaluated as a source of mortality of stocked walleyes. Walleyes will consume centrarchids in lakes lacking other suitable forage (Schneider 1975; Beyerle 1978; Paxton and Stevenson 1978), but little is known about the influence of centrarchid prey densities and size distributions on walleye feeding and growth. In predator-free ponds and small lakes, walleyes had lower survival and grew more slowly with bluegill forage than with cyprinid forage (Schneider 1975; Beyerle 1978). Because centrarchid predators were lacking in these studies, additional information regarding the stocking success of walleyes in small impoundments containing established centrarchid predator and prey populations is needed.

We evaluated survival and growth of walleye fry and fingerlings stocked in an impoundment containing an established centrarchid community. We examined potential sources of mortality of stocked walleyes of various sizes, including stocking stress, predation from largemouth bass, hooking mortality from angling, spillway escapement, and use of forage. In addition, we used relations among production costs for various sized walleyes and estimates of survival to determine the most economical size for stocking. With an understanding of the mechanisms affecting survival of stocked fish and benefit/cost analyses, we make recommendations regarding walleye stocking in centrarchid-dominated systems.

Study Area

Ridge Lake, Illinois (39° 27' N, 80° 09' W) is a 5.6-ha experimental fishing lake with a maximum depth of 6.5 m and mean depth of 2.8 m. Typically, the lake is thermally stratified at a depth of 1-3 m during late May through early September; temperature in the epilimnion ranges from 19 to 33°C and the hypolimnion is anoxic. Mean summer Secchi disk depths are less than 1 m and moderate standing crops of macrophytes exist in the shallow regions. The primary overflow structure, a tower spillway, discharges water from the lake bottom and can also be used to drain the lake. When the capacity of the tower spillway (0.71 $m^3 \cdot s^{-1}$) is exceeded, water is discharged over an auxiliary surface spillway. Both spillways are equipped with downstream weirs (13-mm mesh wire screen) designed to hold emigrating fish alive in water retaining catch baskets.

Methods

Ridge Lake was drained in October 1985 and restocked during 1986 with juvenile and adult largemouth bass (27 kg/ha), bluegills (15 kg/ha), black crappies (Pomoxis nigromaculatus, 5 kg/ha), and channel catfish (Ictaluris punctatus, 13 kg/ha) obtained from area lakes and fish hatcheries. Walleye fry (total length = 9 mm) were stocked in April 1989 and 1990; fingerlings were stocked in May or June (60 mm) and October or November (145 and 215 mm) of each year, 1987-1990 (Table 1). Except for individuals of the smallest size group, all fingerlings were reared in ponds with natural forage. The smallest groups of fingerlings were transferred from ponds to raceways at 50 mm and reared to stocking size (about 60 mm) on artificial feed. Before stocking, a subsample of walleyes was measured (total length, nearest mm), weighed (nearest g), and each fingerling group was marked in each year with unique fin clips (left or right pectoral or pelvic) detectable throughout the study; fry were unmarked. Fish were adjusted to lake temperatures for a minimum of 30 min before stocking. Mean lengths and densities of stocked fry and fingerlings were similar among years, except in 1990 when stocking densities were higher (Table 1). Table 1 near here

Stocking mortality of walleyes was estimated by holding subsamples of fry (N = 100) and fingerlings (N = 30) in suspended cylindrical cages (N = 3 per stocking). Mortality in cages was used to estimate losses associated with hauling, handling, fin clipping and temperature stress. Fry cages were plastic containers (114 L), whereas fingerling cages (942 L) were constructed of 6.4-mm mesh plastic screening. Fry and fingerling cages extended below the lake surface to depths of 0.6 and 1.0 m, respectively. Numbers of dead and live fish were counted after 24 h; we observed no additional mortality after that period.

We assessed losses of stocked fingerlings to predation by examining the stomach contents of largemouth bass, walleyes (from previous stockings), and black crappies on days 1 and 2 poststocking and for 2 additional days during the week after walleyes were stocked; fry were excluded from this assessment because they were too small to accurately identify. Largemouth bass were collected by anglers and electrofishing (3,000-W AC, 230-V, 3-phase), whereas walleyes and black crappies were collected by electrofishing and trap netting (1.8-m x 0.9-m rectangular frame nets, 13-mm bar mesh netting, single 15-m lead). Stomach contents of largemouth bass and walleyes were removed with clear acrylic tubes (Van Den Avyle and Roussel 1980); black crappies were killed for diet analysis.

We estimated population sizes of largemouth bass, walleyes, and black crappies in September and October of each year. Fish were captured for the marking census by electrofishing and trap netting and were recaptured within 1 mo by electrofishing, angling, trap netting and gill netting (monofilament nets, 46 m long x 1.8 m deep consisting of 6 panels with meshes of 19-, 25-, 32-, 38-, 45-, and 51-mm bar mesh). All fish were marked with a fin clip (upper caudal) and the population size of each species or size group was estimated with the Chapman modification of the Petersen formula (Ricker 1975).

Losses of stocked walleyes to predators were estimated for each sample day when samples contained more than 10 individuals of a predator taxon. To estimate the number of walleyes eaten on each day, we divided the number eaten by the number of predators examined, and then multiplied the proportion of predators with walleyes by the estimated number of predators in the population. The minimum length of predator included in each population estimate was determined from the maximum prey:predator length ratio (0.57) found for walleyes eaten by predators in Ridge Lake. Daily estimates were summed to obtain a total estimate of the numbers of stocked walleyes lost to predation (Wahl and Stein 1989).

A creel census measuring total angler effort, catch, and harvest was conducted while the lake was open to public fishing, late April through mid-October. In addition to providing angling statistics, this census allowed us to assess short-term hooking mortality and angling vulnerability of walleyes and to supplement the population estimate and diet samples (Santucci and Wahl 1991). Fishing was by permit only and the lake was open 5 d per week (closed Mondays and Tuesdays). A single entry point provided access and only boat fishing (maximum of 8 boats, 3 persons each) was allowed. The minimum legal length limit for largemouth bass and walleyes was 357 mm. Before fishing, anglers were questioned as to their species preference and they were instructed to keep all boated fish in live wells. Except for walleyes, fish were retrieved at a lake-side laboratory where they were measured (total length, nearest mm) and weighed (nearest g) after which we returned sublegal and unwanted fish to the lake. Anglers were given flags to indicate that a walleye had been caught. Walleyes were retrieved immediately and sublegal and unwanted fish were placed in a floating creel (see previous description of fingerling cages) to determine hooking mortality. After holding overnight (12-15 h), walleyes were measured, weighed, checked for fin clips, and survivors were returned to the lake.

We monitored spillway escapement of walleyes daily when water discharged over either the tower or the surface spillway. Weir catch baskets were checked frequently to avoid losses of retained fish to mammalian or avian predators; we saw no signs that predators were feeding at either spillway weir. Walleyes found in weirs were discarded after they were measured and checked for fin clips.

Walleyes were collected for diet analysis each month during April through November 1988-1989 and April through mid-July 1990 by electrofishing and gill netting. Sampling was discontinued in summer 1990 because gizzard shad (Dorosoma cepedianum) were accidentally introduced into the lake. Length (nearest mm) and weight (nearest g) were recorded for each walleye for determination of growth. Stomach contents were identified to species for fish and to family for invertebrates; volumes were determined by water displacement. To examine size relations between walleyes and their prey, we measured total lengths (TL) of intact fish and standard lengths (SL) of partially digested fish from stomachs of walleyes. For bluegills measured in standard length, total length (range = 10 to 90 mm) was estimated as

$$TL = 1.28(SL) - 0.698, \quad r^2 = 0.99, N = 180.$$

For the comparison of predator and prey length relations, walleyes were grouped into 25-mm length intervals and lengths of ingested bluegills were averaged for each interval.

The size structure and relative abundance of young bluegills, the most abundant forage fish, was estimated in September 1988-1989 from three shoreline rotenone samples spaced equally around the lake. A 4-mm mesh block net (30.5 m long, 1.8 m deep) was deployed to enclose a rectangular area (53-96 m^2) and rotenone was applied in the enclosed area at a 2-3 ppm concentration (Timmons et al. 1979). All recovered fish were counted and a subsample ($N > 200$) was measured.

The abundance of larval bluegills, a potential source of food for young walleyes, was estimated at weekly intervals at night from April through August, 1987-1990. Two Miller high-speed samplers (1.6 m long, 14-cm diameter, 0.5-mm mesh) were towed from the bow of a boat at about 2 $m \cdot s^{-1}$; a calibrated flow meter was used to estimate the volume of water filtered. Oblique tows sampled from the surface to a depth of 4 m along a transect on the central axis of the lake. All larvae were preserved in 95% ethanol, identified to species, and counted. In addition to providing estimates of larval bluegill abundance, ichthyoplankton samples provided evidence that no walleyes reproduced during the study.

We obtained estimates of costs of walleye fry and fingerlings from several sources including commercial producers (American Fisheries Society 1982), and public extensive and intensive culture facilities. Walleyes produced extensively are those raised on natural foods in ponds; intensive culture comprises fish raised on artificial feeds in raceways or tanks. All estimates included both direct and indirect costs of rearing. To assess which walleye size group was the most economical to stock, we used the estimated costs of rearing to determine the total cost for each stocking. Dividing the numbers of walleyes surviving after 1 and 2 y by the total cost and averaging these values across years provided mean costs per surviving walleye. Walleye survival estimates were based on the total number of walleyes stocked, unadjusted for initial mortality. To determine the cost per walleye caught by anglers, we followed this same procedure substituting numbers caught by anglers for numbers surviving. We used the number of walleyes caught by anglers for this assessment because numbers harvested during the study were low.

Except where indicated, statistical analyses were one-way analysis of variance (ANOVA) for randomized complete block designs (blocked by year) and Tukey's multiple comparisons which allowed us to identify differences among size groups. An arcsine transformation was used on percentage data to stabilize the variance before statistical tests were completed (Steel and Torrie 1980).

Results

Survival.--Survival of walleye fry and the smallest group of fingerlings was extremely low; only 1 individual from each of these size groups was recovered in 4 yr of extensive electrofishing, shoreline rotenone, trap net, gill net, seining, and angling collections. For fingerlings, survival 1 yr after stocking differed among size groups (ANOVA, $F = 20.82$, df = 2,4, $P = 0.008$; Fig. 1A). Fig. 1 near here

Across years, large fingerlings (mean survival = 31%) had higher survival than small fingerlings (0%; Tukey's multiple comparisons, $T = 0.31$, $P = 0.007$). Survival was intermediate for medium fingerlings (7%), but was not different from either the large ($T = 0.04$, $P = 0.06$) or small size groups ($T = 0.07$, $P = 0.09$).

Compared to estimates after 1 yr, survival of medium and large fingerlings was lower 2 yr after stocking (Fig. 1B). Mean survival of walleyes stocked in 1987 and 1988 declined from 6% to 4.5% for medium fingerlings and from 20% to 10% for large fingerlings. Despite the decline in survival for these larger size groups, patterns of survival observed 1 yr after stocking were also apparent the second year after stocking. After 2 yr, mean survival was highest for walleyes stocked as large fingerlings (10%), followed by those stocked as medium fingerlings (4%) and then small fingerlings (0%; $\underline{T} > 0.01$, $\underline{P} < 0.05$).

Creel census data reinforced the patterns of survival observed after stocking. Anglers caught a higher percent of walleyes from the large size group (mean percent of number stocked = 91%) than from either the medium (9%) or small size groups (0%; $\underline{T} > 0.60$, $\underline{P} < 0.03$; Fig. 1C). Differences between the means of the small and medium groups did not differ ($\underline{T} < 0.17$, $\underline{P} > 0.1$). To assess the influence of multiple recaptures on the angler catch, we marked walleyes after they were caught by clipping dorsal spines and then counted the number of times they were recaptured. From this mark-recapture technique, we estimated that 33% of the walleyes caught by anglers were caught more than once. These high initial catches and recapture rates occurred when fishing pressure was high at Ridge Lake (914-1003 angler-h$\cdot$ha^{-1}). However, angler effort directed toward walleyes was low (<10 angler-h$\cdot$ha^{-1}).

Factors influencing survival.--Mortality from stocking stress influenced first-year survival of stocked walleyes in Ridge Lake. Stocking mortality was higher for fry (mean stocking mortality = 20%) and small fingerlings (22%) than for either the medium (1%) or large fingerlings (1%; $\underline{T} > 0.04$, $\underline{P} < 0.005$; Table 2). Fry and small fingerlings stocked in spring and early summer were exposed both to higher water temperatures at stocking and greater temperature changes between hatchery and lake than the larger fingerlings stocked in fall (Table 2). However, thermal stress did not explain all of the differences in stocking mortality because we observed a large difference in mortality of small fingerlings in 1989 (7%) and 1990 (55%) when the lake temperature was similar (27°C). Table 2 near here

Neither walleyes nor black crappies appeared to prey heavily on stocked walleye fingerlings. Only 5 walleyes from the small size groups were found in other walleye stomachs (N = 72 examined), and none were found in black crappie stomachs (N = 121). Furthermore, estimated densities of walleyes (<13$\cdot$ha^{-1}) and black crappies (<1$\cdot$trap net-d^{-1}, effort > 45 net-d$\cdot$yr^{-1}) were low during the study.

In contrast to other predators, substantial numbers of walleye fingerlings were recovered from largemouth bass stomachs. Losses to largemouth bass predation were higher for the small and medium walleyes (mean percent of number stocked = 6 and 17%, respectively) than for the large fingerlings (0%; $\underline{T} > 0.06$, $\underline{P} < 0.005$; Table 3). The low estimated predation on the small size group in 1989 occurred despite the fact that the number of largemouth bass capable of eating these fish was high ($N = 165 \cdot ha^{-1}$) and that we examined more largemouth bass (N = 303, 33% of the estimated population) than in other years (N = 117-256, 9-22%). For the largest size group, few largemouth bass ($N < 15 \cdot ha^{-1}$) in any year were large enough to eat these walleyes. Predation by largemouth bass on stocked walleyes did not appear to be related to the density and size structure of the largemouth bass population. We did not find a relationship between the percent of stocked fish eaten and the density of largemouth bass of effective predatory size (linear regression, $\underline{r}^2 = 0.10$, $\underline{P} = 0.33$).

Table 3
near here

Vulnerability of walleyes to largemouth bass was highest immediately after stocking. Of all the walleyes recovered from largemouth bass stomachs in the week after stocking, 76% were eaten within 48 h of stocking. However, we also found evidence of longer-term predation by largemouth bass on walleyes in 1989 and 1990. Small numbers of walleyes from the medium size groups stocked in fall 1988 and 1989 (N = 3 and 2, respectively) were found in largemouth bass stomachs up to 7 mo after they were stocked. However, because of the small number of walleyes recovered, we were not able to quantify the impact of long-term predation on walleye survival.

We observed moderate losses of walleyes (14%) that were caught by anglers and released into holding cages. Nearly all fish that died in the cages did so within 1 h of being caught. For all years combined, hooking mortality did not differ among sizes (Fig. 2; chi-square, $\underline{P} = 0.54$), but losses were higher for walleyes caught with live bait (18%, 95% C.I. = 13-23%) than for those caught with artificial lures (5%, 1-9%; chi-square, $\underline{P} = 0.002$). As a source of losses of stocked fish, hooking mortality varied between size groups. Both within and among years, hooking mortality as a percent of walleyes stocked was higher for large fingerlings (4-12%) than for medium (0.3-2%) size groups (chi-square, $\underline{P} < 0.03$). These differences between size groups were not

Fig. 2
near here

related to size at capture, but resulted from lower stocking densities and higher catches of individuals from the large size groups.

Escapement losses were a small fraction of the number of walleyes stocked (<2%); only 10 individuals were collected in the surface spillway weir and 11 in the tower spillway weir. All emigrating fish were from the medium and large fingerling stockings.

Diets and growth.--A moderate percent of the walleye stomachs (N = 102) examined from 1988 through mid-1990 were empty (42%). Diet analyses of young-of-year was precluded by low survival of fry and small fingerlings and late fall stockings of the larger size groups. However, ichthyoplankton tows indicated that larval bluegills (<15 mm) were available as prey from May through mid-August of each year; mean densities (±95% confidence intervals) ranged from 12±6 to 64±45 larvae$\cdot m^{-3}$. For age-1 and older walleyes, bluegills made up a higher proportion of the diet (87% of the volume; chi-square, partitioned degrees of freedom, $P = 0.0005$) and occurred in more of the stomachs containing food (84%) than all other prey. Primarily juvenile bluegills (16-90 mm) were eaten. Adult bluegills (>90 mm) were not eaten and larval bluegills were found in only a small proportion of walleyes (<2% of the volume; frequency < 10%). We did not find differences in diets among years (chi-square, $P = 0.20$), but diets of walleyes in the fall differed from those earlier in the year (chi-square, partitioned degrees of freedom, $P = 0.004$) because only young bluegills were eaten in fall. In spring and summer, other fish (including largemouth bass, black crappies, and unidentifiable fish remains) and invertebrates combined to make up 13% of the volume of the diets.

We observed differences in growth between size groups of stocked walleyes. Individuals from the medium and large size groups grew from spring through fall, but growth slowed in winter (Fig. 3). Because growth rate was higher for the medium size group, mean lengths converged in 24 to 30 mo for walleyes stocked in 1987 and in 12 to 18 mo for those stocked in 1988. In addition to the growth rate difference between size groups, growth rates differed between years. Walleyes from the large size groups were larger after the 1988 growing season (mean length = 327 mm) than after the 1989 season (269 mm; t-test, $P = 0.001$). Likewise, first year growth of the

Fig. 3 near here

medium size groups was faster in 1988 (mean length = 266 mm) than 1989 (253 mm; t-test, P = 0.01).

Differences in abundance and size distribution of young bluegills between years may explain the patterns of growth observed for various size groups of walleyes within and between years. There was a positive relationship between mean lengths of ingested bluegills and lengths of walleyes (160-380 mm) in 1988 (Pearson correlation, r^2 = 0.72, P = 0.05; Fig. 4A), but not in 1989 (Fig. 4B). The size of available prey may have limited growth rates of larger walleyes during 1989. Our estimates of bluegill abundance in the lake also varied among years. Whereas densities of 10- to 34-mm bluegills in shoreline rotenone samples did not differ between 1988 and 1989 (mean densities = 31.2 and 9.3 bluegills$\cdot m^{-2}$, respectively; t-test, P = 0.15), densities of larger bluegills in these samples (35-70 mm) were higher in 1988 (8.9 bluegills$\cdot m^{-2}$) than in 1989 (1.3 bluegills$\cdot m^{-2}$; t-test, P = 0.0002).

Fig. 4 near here

To further examine the relationship between forage base and growth, we compared literature values for growth rates of walleyes from several lakes. For these comparisons, we choose lakes that 1) were located in the north-central region of the USA, 2) had the principal forage species identified, and 3) had growth data available for walleyes ages 0 through 3. Growth rates in Ridge Lake (1987 stocking) were similar to those of walleyes from other waters having centrarchid and other spiny-rayed prey species (two-way ANOVA:, F = 0.67, df = 1,11, P = 0.40; Table 4). Length increments in lakes with gizzard shad or cyprinids were higher than those of walleyes from lakes with spiny-rayed forage (F = 20.04, df = 1,31, P = 0.001). On average, walleyes from gizzard shad and cyprinid waters were larger at age 0 and had faster growth rates than those from centrarchid lakes during each subsequent year.

Table 4 near here

Benefit/cost analysis.--We found substantial differences in the estimated initial cost of walleyes among sources; costs were lowest for extensively reared fish and were highest for those purchased commercially (Table 5). For each source except extensive culture, production costs increased approximately two-fold for walleyes reared to each successively larger size. Costs per survivor after 1 and 2 yr were higher for medium fingerlings than for large fingerlings from all

Table 5 near here

sources (Table 5). Costs per angler-caught walleye were highest for small fingerlings followed in order by medium and large fingerlings. Costs per survivor and cost per fish caught were substantially higher for intensively, as compared to extensively reared walleye, but as expected, both were much lower than for fish purchased from commercial facilities. For all sources and all estimates of survival, large fingerlings (186-216 mm) were the most economical walleyes to stock.

Discussion

Mechanisms Influencing Survival.

Based on survival rates, stocking success of walleyes in small centrarchid-dominated lakes will be low for fry and small fingerlings and moderate for larger fingerlings. In predator-free ponds and small lakes containing bluegills, survival of walleye fingerlings (100 mm) was also moderate (Schneider 1975; Beyerle 1978). Low survival in centrarchid waters may be related to prey availability. Jennings and Philipp (1992) observed a positive correlation between the success of walleye fry stockings and the density of small cladocerans. Because fish may become the major food of walleyes as small as 30-40 mm (Maloney and Johnson 1957; Johnson et al. 1988), the abundance of larval and juvenile fish may influence survival of walleye fingerlings more than zooplankton densities. Prey density was not a likely factor influencing survival of stocked walleye fingerlings in Ridge Lake because larval and juvenile bluegills were present in high numbers throughout the summer and fall of each year. However, previous work has shown that prey type can influence survival; Schneider (1975) and Beyerle (1978) observed lower survival of walleyes with bluegills than with minnows even though the density of edible-sized bluegills was higher than that of minnows. While low to moderate survival of walleyes may be typical with bluegill prey, our results also indicate that other factors contributed to mortality of stocked walleyes.

The size and time of year walleyes are available for stocking may influence initial mortality. Although we found mortality associated with thermal stress at stocking to be higher for smaller than for larger walleyes, the fry and small fingerlings were always stocked at higher lake temperatures than the medium and large fingerlings. However, thermal stress does not explain all of the differences in stocking mortality because we found within size group differences in mortality unrelated to temperature. Factors potentially influencing survival of other stocked species, such as condition and health at stocking (Belusz 1978) and hauling or handling stress (Johnson and Metcalf 1982; Carmichael et al. 1984; Mather and Wahl 1989), might have caused higher losses of the smaller size groups of walleyes.

Predation by largemouth bass was an important source of mortality for walleyes. Small and medium size groups consistently experienced higher losses to predation and lower survival than large fingerlings. The absence of small fingerlings from stomachs in 1989 may have occurred because these walleyes were smaller, were digested more quickly, or were in better condition than those stocked in other years. Temperature may have also biased our estimates of predation losses. We assumed that predator stomach contents represented 1 d of feeding. Shorter evacuation rates (<24 h at ≥27°C; Hunt 1960; Beamish 1972) would result in underestimates of the numbers of small fingerlings eaten, whereas longer evacuation rates (>24 h at ≤15°C) would result in overestimates of the numbers of medium fingerlings consumed. As a result, our estimates of differences in losses to predation among size groups are conservative. Regardless, higher losses for the smaller size groups indicate that vulnerability to largemouth bass was related to size at stocking. Because relationships between size and vulnerability to predation have also been observed for a variety of other stocked species (Krummrich and Heidinger 1973; Shireman et al. 1978; Stein et al. 1981; Wahl and Stein 1989), evaluations of predator populations before stocking appear warranted.

We anticipated that losses would also be related to predator density because the density of largemouth bass capable of consuming each successively larger walleye size group declines. However, we did not observe a relation between these variables in Ridge Lake. In contrast, Carline et al. (1986) observed a strong positive correlation between losses of stocked tiger muskellunge (<u>Esox masquinongy</u> X <u>E. lucius</u>) and largemouth bass densities. Relationships were developed from 14 stockings in 6 different lakes. With additional lakes and differing predator populations, a stronger link between walleye losses and predator density and size structure may be found.

The effect of angler exploitation on walleye survival was minimal during our study because most walleyes had not attained legal size. However, we did observe moderate losses of walleyes that were caught and released by anglers. These losses are consistent with estimates of hooking mortality reported for walleyes in Minnesota ponds (Payer et al. 1989), but are above those reported in other lakes (Schaefer 1989). As a percent of walleyes stocked, hooking mortality does not explain the pattern of higher survival for larger fish; losses were higher for the large size groups than for the medium size groups. However, hooking mortality does account for a portion of total mortality and may, in part, explain the decline in walleye survival between the first and second years after stocking.

We observed high angler catches and recaptures of walleyes despite the low effort directed toward this species. Walleyes were not only highly vulnerable to angling, but they were vulnerable to anglers fishing for other species. Because angler exploitation rates increase with decreasing walleye age and length (Serns and Kempinger 1981), the small size (most were <350 mm) and young ages (age-3 and less) of walleyes available during our study may partially explain the high catch rates. However, high angling vulnerability may be typical for walleyes in small lakes because of the relative ease with which fish can be located (Beyerle 1978). Also, angler exploitation rates can be high when prey availability and walleye growth rates are low (Forney 1967). If slow growth is typical for walleyes in impoundments containing centrarchid forage, then walleye catchability may also be high in these lakes.

Losses of walleyes through reservoir discharges are well documented (Walburg 1971; Smith and Andersen 1984; Jernejcic 1986) and may result in substantial population declines in a lake (Groen and Schroeder 1978). Escapement losses probably depend on spillway design and flow rates. Survival of walleye fry has been shown to be influenced by lake discharges (Willis and Stephen 1987). The high watershed to lake surface area ratio (66:1) in Ridge Lake can result in substantial discharges. We observed high discharges within 2 wk of each fry stocking, but were not able to assess losses due to the small size of fry at stocking. Although spillway escapement was not a major factor effecting the survival of walleye fingerlings, it may have been important for walleye fry.

Prey Selection and Growth.

In small impoundments where soft-rayed prey is often lacking, abundant species such as bluegills will be an important food of walleyes. Young bluegills were more abundant (11-40 bluegills$\cdot m^{-2}$) than other potential fish prey (<0.2 fish$\cdot m^{-2}$) and were the principal food of walleyes in Ridge Lake. Bluegills were also found to be an important food item in other lakes where the abundance of alternative prey was limited (Dendy 1946; Paxton and Stevenson 1978) or where bluegills were the only piscine prey available (Schneider 1975; Beyerle 1978; Forsythe and Wren 1979). In contrast, diets of walleyes from lakes with soft-rayed and spiny-rayed forage fishes contained higher percentages of minnows or clupeids than centrarchids (Range 1973; Boaze and Lackey 1974; Goddard and Redmond 1978; Johnson et al. 1988). Relative abundance and availability of these prey may have influenced walleye prey selection; however, evidence from at least some lakes suggests that walleyes will select for soft-rayed taxa even when spiny-rayed forage is abundant (Parsons 1971; Wagner 1972; Knight et al. 1984).

The species available as prey may influence not only diet but growth of walleyes. Comparing across several lakes, we found that walleye growth rates were slower in lakes with bluegills or other spiny-rayed prey species than in lakes predominated by gizzard shad or cyprinids. Because lakes with clupeids or cyprinids were larger than those with centrarchids, differences in available habitat among lakes may also have influenced walleye growth. However, previous pond and small lake studies have demonstrated slower growth of walleyes with bluegills than with minnows as prey (Schneider 1975; Beyerle 1978). Extensive work with esocids has shown that forage species have inherent differences that can affect growth of predators. Esocids exhibit slower growth in centrarchid impoundments compared to gizzard shad (Weithman and Anderson 1977, Newman and Storck 1986, Wahl and Stein 1988) or fathead minnow impoundments (Gillen et al. 1981). Wahl and Stein (1988) suggested that esocid growth was slower because predators benefit less from bluegill prey; the caloric content of bluegills was lower and the costs of capture were higher than those of gizzard shad and minnows. Capture costs were influenced by prey morphology (body depth and the presence or absence of spines) and antipredatory behavior (Gillen et al. 1981; Moody et al. 1983; Wahl and Stein 1988). These inherent differences among prey species may explain, in part, the observed growth patterns of walleyes among lakes with centrarchid and soft-rayed forage. However, further studies are needed to determine the specific effects of prey morphology, behavior, and energy content on walleye growth.

In lakes lacking soft-rayed forage species, bluegill abundance and size structure may influence walleye diet and growth. Diet analyses from lakes with a diverse size range of abundant prey indicate that walleyes are size selective and that prey size typically increases with walleye size (Parsons 1971; Knight et al. 1984; Johnson et al. 1988). We found a positive predator:prey length relationship for walleyes and bluegills during one year, but not in another. Differences between years appeared to be related to the availability of preferred sizes of bluegills. The availability of appropriate-sized bluegills also appeared important in determining growth of walleyes. Walleyes from medium and large size groups grew at similar rates when a range of bluegill sizes were available, but growth of larger walleyes was reduced when primarily small bluegills were present. Although bluegill populations with a high relative abundance of small individuals may be typical in some small impoundments (Coble 1988), bluegill abundance and size structure will likely vary among lakes and years. Predicting walleye growth in these lakes will depend on our understanding of the factors influencing bluegill populations, such as environmental conditions (Stevenson et al. 1969), angling (Coble 1988), competition (Gerking 1966; Werner and Hall 1977), or predation (Mittelbach 1984).

Management Implications.

The success of walleye stocking programs will depend largely on the survival and growth of stocked fish. Considerable variation has been observed in survival of stocked walleyes among lakes (Laarman 1978; Ellison and Franzin 1992), across years within a lake (Schneider 1983; Jennings and Philipp 1992), and with size at stocking (Laarman 1981; Heidinger et al. 1985;

Koppelman et al. 1992). Due to this variability, the success of any walleye stocking practice is largely unpredictable. Further complicating our understanding of walleye stocking success is the fact that variables affecting survival have typically not been identified. Our ability to improve the success and consistency of walleye stocking practices depends on increased understanding of the variables governing survival of stocked walleyes. We found large fingerlings to have higher survival than smaller fingerlings or fry, and that thermal stress at stocking and predation by largemouth bass were more important than hooking mortality or spillway escapement in determining walleye survival. By stocking walleyes at least as large as 200 mm in the fall when lake temperatures have declined, we were able to reduce losses to largemouth bass predation and to thermal stress. Although initial costs are substantially higher for these large fingerlings compared to smaller fingerlings or fry, return on investment increased with walleye size and 200 mm fingerlings were the most economical walleyes to stock. Unfortunately, growth of stocked walleyes in small impoundments with centrarchid forage will be slower than walleyes in lakes with other prey populations.

Survival of walleyes stocked in some lakes has declined with successive stockings due to predation by survivors from prior stockings (Beyerle 1978; Schneider 1983), and has resulted in recommendations that fingerling walleyes not be stocked in consecutive years. We did not observe reduced survival for successive walleye stockings because predation by largemouth bass was consistent across years and predation by walleyes was low. By stocking walleyes >200 mm, losses to the majority of resident predators may be reduced and stocking in consecutive years may be warranted. However, the effects of predator size-structure and abundance on walleye survival rates may modify these recommendations.

The high vulnerability of walleyes to angling in Ridge Lake and other small lakes (Beyerle 1978, Schneider 1979) indicates that exploitation could be high in these waters. Moderate hooking mortality for walleyes suggests that protective size limits may lower fishing mortality. Minimum length limits are not recommended for populations having slow growth because densities of sublegal walleyes may increase and further reduce growth rates (Serns 1978;

Brousseau and Armstrong 1987). Slow growth in centrarchid impoundments may make protective slot limits more effective for managing walleyes in these waters. Increased stocking densities may be warranted when protective slot regulations are enforced because anglers are allowed to harvest the smaller, more easily caught walleyes in the population. Lower losses of walleyes caught with artificial lures in our work and by others (Payer et al. 1989) suggest restrictions on the use of live bait may be useful in reducing losses of walleyes where size limits are enforced.

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Table 1. Number, density, and mean total length (N≥50) of walleye fry and three size groups of fingerlings stocked in Ridge Lake, Illinois, 1987-1990.

Year	Date	Size group	Number	Density ($fish \cdot ha^{-1}$)	Mean length ±95% C.I. (mm)
1987	18 Jun	Small	675	120	61±1.4
	3 Nov	Medium	364	65	142±2.0
	3 Nov	Large	120	21	208±4.5
1988	20 Jun	Small	765	137	61±1.6
	7 Nov	Medium	337	60	145±2.3
	7 Nov	Large	145	26	216±3.7
1989	27 Apr	Fry	14,000	2,500	9±0.1
	31 May	Small	670	120	48±1.2
	20 Nov	Medium	385	69	132±1.5
	21 Nov	Large	81	14	186±3.1
1990	25 Apr	Fry	30,000	5,357	9±0.2
	25 Jun	Small	702	125	56±1.1
	20 Oct	Medium	237	42	140±2.4
	20 Oct	Large	260	46	211±2.2

Table 2. Mean losses (±95% confidence intervals) of walleye fry and three size groups of fingerlings due to hauling, handling, and temperature stress from four stockings in Ridge Lake, Illinois, 1987-1990 (fry were not stocked in 1987 or 1988). Mortality was estimated for each stocking by holding subsamples of walleyes (N = 30 fingerlings or N = 100 fry per cage) in cylindrical cages (N = 3) suspended in Ridge Lake for 24 h; fish were tempered for 30 min before stocking. Water temperature was recorded at 10 cm at stocking.

Group (mean length, mm)	Mortality (%)	Lake temperature at stocking (°C)	Temperature change from hatchery (range °C)
Fry (9)	20±1	22±6	+10 to +11
Small (48-61)	22±9	28±24	+3 to +8
Medium (132-145)	1±2	12±6	-1 to +2
Large (186-216)	1±1	12±6	-3 to +2

Table 3. Estimated numbers of stocked walleye fingerlings eaten by largemouth bass in Ridge Lake, Illinois, 1987-1990. Estimates of predatory mortality were obtained on each sampling date by multiplying the number of walleyes per largemouth bass stomach collected by night electrofishing by the number of largemouth bass in the population (ranges were determined from 95% C.I.). Summing these daily values provided a minimum estimate of the total number of walleyes eaten. Minimum lengths of largemouth bass included in the population estimates were based on the maximum prey:predator length ratio (0.57) found for walleyes and largemouth bass in Ridge Lake. Population estimates and 95% confidence intervals are based on Petersen estimates (Ricker 1975), except as noted.

Year	Walleye mean length (mm)	Minimum largemouth bass length (mm)	Largemouth bass population estimate (95% C. I.)	Number of largemouth bass examined	Estimated number of walleyes eaten (range)	Percent of stocked walleyes eaten (range)
1987	61	107	1,261 (903-1,826)	117	77 (55-111)	11 (8-16)
	142	249	545 (327-965)	21	42 (25-74)	12 (7-20)
	208	366	57[a]	6	0	0
1988	61	107	1,130 (832-1,575)	256	73 (46-88)	10 (6-12)
	145	254	380 (248-608)	104	23 (15-36)	7 (4-11)
	216	376	16 (6-39)	5	0	0

Table 3. Continued.

1989	48	84	925 (688-1,271)	303	0	0
	132	231	712 (501-1,047)	46	89 (63-131)	23 (16-34)
	185	325	74 (44-131)	9	0	0
1990	56	98	549 (421-717)	125	79 (60-103)	11 (8-15)
	140	246	274 (199-388)	38	67 (49-95)	28 (21-40)
	211	370	9[a]	2	0	0

[a] Population estimates are based on the proportion of largemouth bass of all sizes greater than the minimum length.

Table 4. Annual length increments (mm) for walleyes ages 0 through 3 from Ridge Lake and other selected lakes and reservoirs. The two sets of values for Ridge Lake are for medium and large walleyes stocked in 1987. Lakes chosen for comparison had the most abundant forage species identified and were located in the north-central region of the USA.

Water body (Source)	Surface area (ha)	Age 0	Age 1	Age 2	Age 3	Available forage
Ridge Lake, Illinois (present study)	6	142	125	60		centrarchids
		208	119	24	50	
Jewet Lake, Michigan (Schneider 1983)	5	139	155	45	9	yellow perch
Killdeer Reservoir, Ohio (Paxton and Stevenson 1978)	115	173	92	23	49	centrarchids, yellow perch
Ferguson Reservoir, Ohio (Paxton and Stevenson 1978)	123	181	53	59	37	centrarchids, yellow perch
Clinton Lake, Illinois (IDOC 1986-1988)[a]	2,024	199	140	63	109	gizzard shad
Stockton Lake, Missouri (Goddard and Redmond 1978)	10,072	310	142	33	114	gizzard shad
Pleasant Hill Reservoir, Ohio (Johnson et al. 1988)	344	240	132	84	63	gizzard shad

Table 4. Continued.

Lake Erie, Ohio (Van Vooren and Davies 1974)	2.57×10^6	205	166	72	51	gizzard shad, cyprinids
McConaughy Res., Nebraska McCarraher et al. 1971)	14,560	185	167	113	57	gizzard shad

[a] G. Lutterbie, Illinois Department of Conservation, pers. comm.

Table 5. Initial costs per individual (1989 US$), costs per survivor 1 and 2 yr after stocking (mean of 3 yr), and cost per individual caught by anglers for three sources of walleye fry and three sizes of fingerlings stocked in Ridge Lake, Illinois, 1987-1989. Numbers of walleyes surviving and numbers in the angler catch were determined from mark-recapture population estimates and a creel census, respectively. NC indicates no walleyes were collected.

	Intensive culture[a]				Extensive culture[b]			
Size group (mean length, mm)	Initial cost per walleye	Cost per survivor at 12 mo	Cost per survivor at 24 mo	Cost per walleye caught by anglers	Initial cost per walleye	Cost per survivor at 12 mo	Cost per survivor at 24 mo	Cost per walleye caught by anglers
Fry (9)	0.008	NC	NC	NC	0.001	NC	NC	NC
Small (48-61)	0.016	NC	NC	33.76	—	NC	NC	—
Medium (132-145)	0.36	4.89	10.34	5.67	0.05	0.68	1.44	0.79
Large (186-216)	0.80	3.18	6.4	1.13	0.05	0.20	0.40	0.07

[a] S. Stuewe, Illinois Department of Conservation, pers. comm.

[b] J. Daly and B. Parsons, Minnesota Department of Natural Resources, pers. comm.

[c] American Fisheries Society (1982).

Table 5. Extended.

Commercial cost[c]			
Initial cost per walleye	Cost per survivor at 12 mo	Cost per survivor at 24 mo	Cost per walleye caught by anglers
—	NC	NC	NC
0.52	NC	NC	1097.20
1.18	16.03	33.90	18.57
2.06	8.19	16.54	2.91

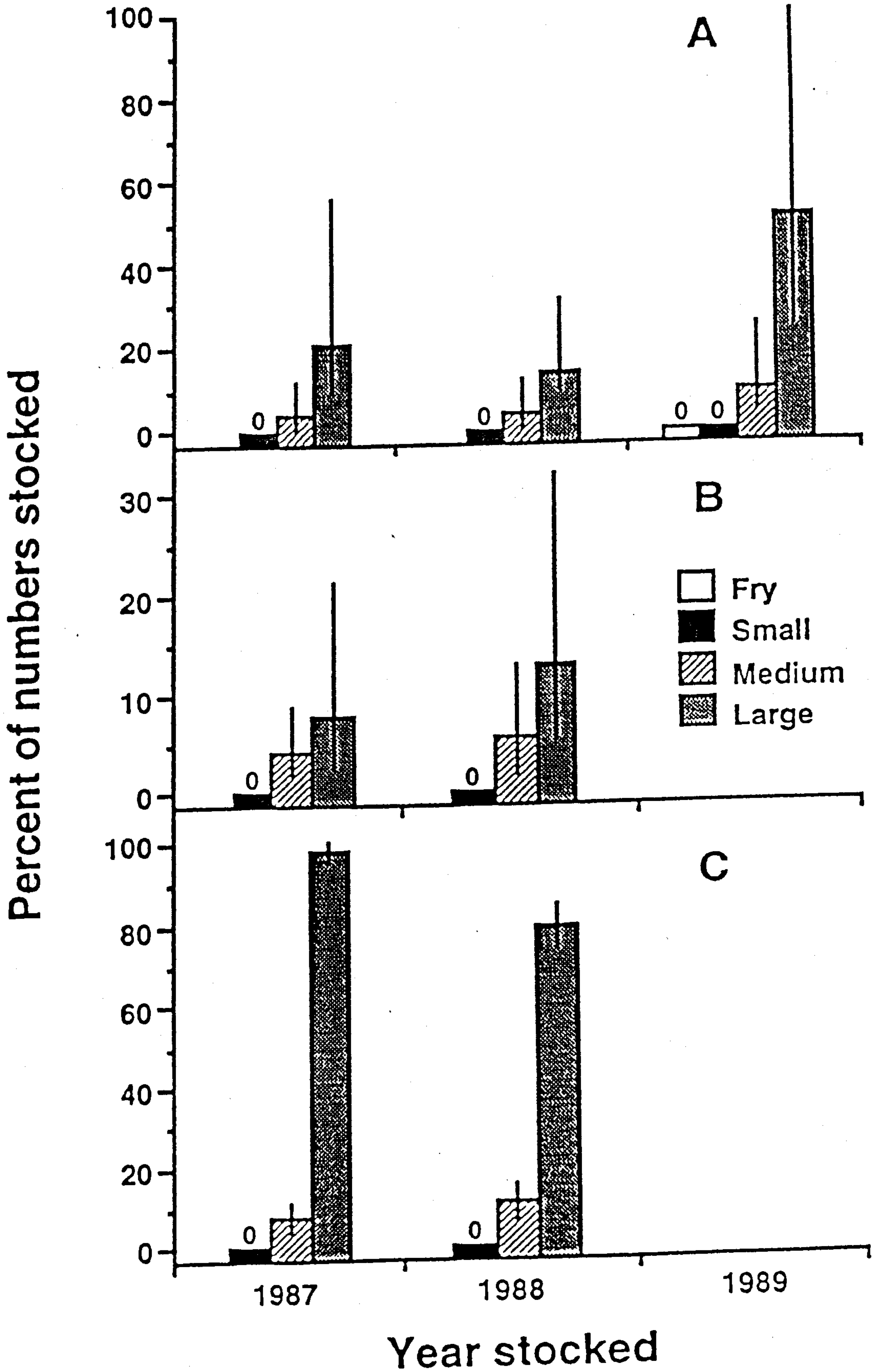
Figure captions

Fig. 1. Survival of walleyes in fall during the first (A) and second (B) years after stocking and percentages of stocked walleyes caught by anglers (C) in Ridge Lake, Illinois. Walleyes were stocked as small (48- to 61-mm), medium (132- to 145-mm), and large (186- to 216-mm) fingerlings in 1987, 1988, and 1989; fry (mean length = 9 mm) were stocked in 1989. Values are percent survival of initial numbers stocked based on Petersen mark-recapture population estimates; angler catch data were obtained from a creel census during 1988-1990. Vertical lines represent 95% confidence intervals. Note different scales on each panel.

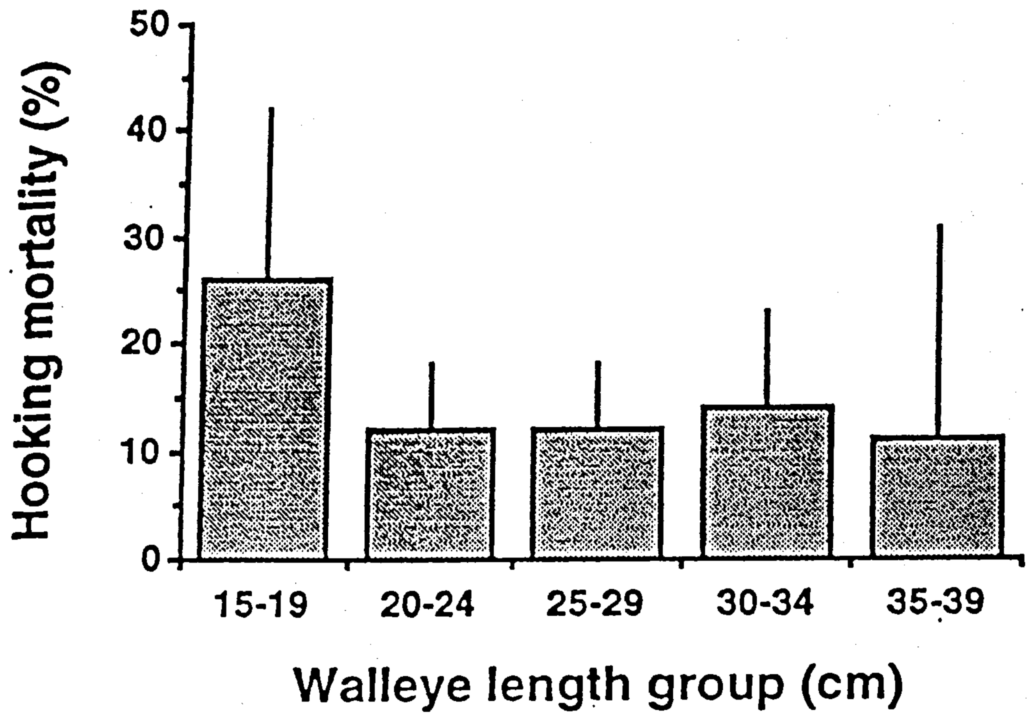
Fig. 2. Angler induced mortality for 5-cm size groups of walleyes (15-39 cm) as a percent of the total catch in Ridge Lake, Illinois, 1988-1990. Vertical lines represent Clopper-Pearson 95% confidence intervals.

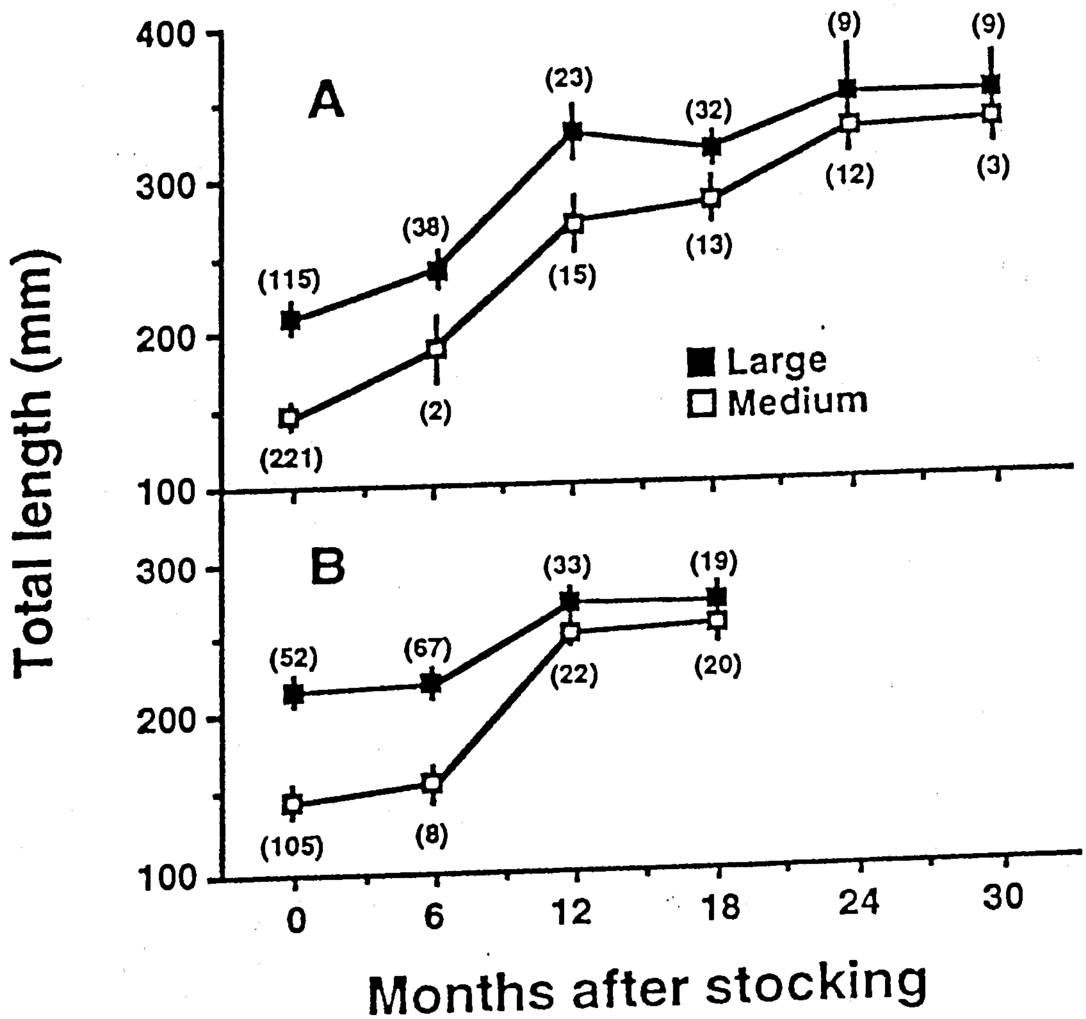
Fig. 3. Mean total lengths of medium (132- to 145-mm) and large (186- to 216-mm) walleye fingerlings following stocking in November 1987 (A) and 1988 (B) in Ridge Lake, Illinois. Walleye growth was assessed at 6-mo intervals corresponding to May and October each year after stocking. Vertical lines represent 95% confidence intervals; sample sizes are in parentheses.

Fig. 4. Mean total lengths for bluegills eaten by walleyes during 1988 (A) and 1989 (B) in Ridge Lake, Illinois. Data for walleyes were combined within 25-mm length intervals. Walleyes were collected monthly from April through November by electrofishing.

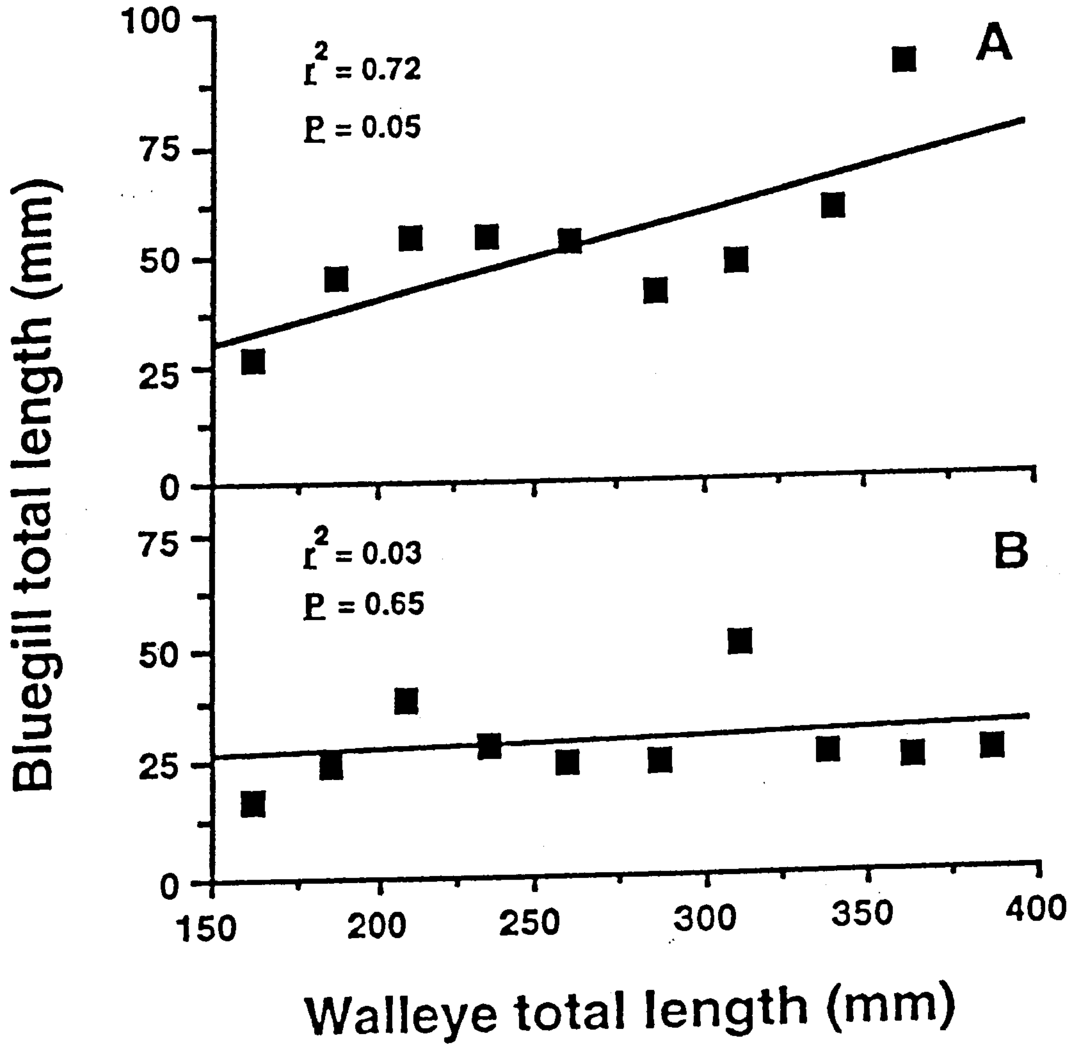


A
B
C
Percent of numbers stocked
100
80
60
40
20
0
30
20
10
0
0
0
0
0
0
0
0
0
Fry
Small
Medium
Large
1987
1988
1989
Year stocked


50
40
30
20
10
0
Hooking mortality (%)
15-19
20-24
25-29
30-34
35-39
Walleye length group (cm)



Total length (mm)
400
300
200
100
A
(115)
(38)
(23)
(32)
(9)
(9)
(221)
(2)
(15)
(13)
(12)
(3)
Large
Medium
B
(52)
(67)
(33)
(19)
(105)
(8)
(22)
(20)
0
6
12
18
24
30
Months after stocking



A
B
r^2 = 0.72
P = 0.05
r^2 = 0.03
P = 0.65
Bluegill total length (mm)
Walleye total length (mm)
100
75
50
25
0
75
50
25
0
150
200
250
300
350
400

APPENDIX B

Growth, mortality, harvest, and cost-effectiveness of stocked channel catfish in a small impoundment

Victor J. Santucci, Jr.[1]

Ridge Lake Station, Illinois Natural History Survey,

Rural Route 1, Box 233, Charleston, Illinois 61920, USA

David H. Wahl

Center for Aquatic Ecology, Illinois Natural History Survey and

Department of Ecology, Ethology, and Evolution, University of Illinois,

607 E. Peabody Drive, Champaign, Illinois 61820, USA

Ted W. Storck[2]

Ridge Lake Station, Illinois Natural History Survey,

Rural Route 1, Box 233, Charleston, Illinois 61920, USA

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[1] Present address: Max McGraw Wildlife Foundation, Post Office Box 9, Dundee, Illinois 60118, USA.

[2] Present address: 137A Hunt Club Lane, Raleigh, North Carolina 27606, USA.

Abstract.--We compared mortality and harvest of 200- and 250-mm channel catfish Ictalurus punctatus stocked in equal numbers for 4 years in an impoundment containing largemouth bass Micropterus salmoides and bluegill Lepomis macrochirus populations. Based on a 5-year creel census, 52 to 92% of stocked fish were harvested. We found no difference between the stocked length groups in terms of mean number caught (N = 365 for 200 mm and 392 for 250 mm), mean number harvested (66% for 200 mm and 83% for 250 mm), or mean total weight harvested (116 kg for 200 mm and 164 kg for 250 mm). An evaluation of potential mechanisms influencing survival of stocked channel catfish showed stocking mortality, largemouth bass predation, hooking mortality, and spillway escapement were low for both length groups in all years. Harvest was the most important source of mortality in these populations. Growth rates were high and within years did not differ between length groups. High exploitation, fast growth, and low hooking mortality suggest length limits may be useful for deferring harvest of channel catfish in small impoundments until they reach a larger size. Based on analysis of cost effectiveness (catch and harvest/cost of stocking), the return on investment was similar for fish from both length groups. Consequently, we do not recommend stocking channel catfish larger than 200 mm for most put-grow-and-take fisheries.

Because natural recruitment of channel catfish Ictalurus punctatus in small impoundments is often low or nonexistent (Marzolf 1957; Davis 1959), restocking is necessary to sustain an acceptable sport fishery. In lakes with established predator populations, survival of stocked fish may also be low (Crance and McBay 1966; Powell 1976; Mestl 1983). Survival of channel catfish can be increased in waters with resident piscivores by increasing the size of stocked fish (Krummrich and Heidinger 1973; Storck and Newman 1988). However, high mortality of fish as large as 200 mm total length (up to 73%; Storck and Newman 1988) indicates that a further increase in size at stocking could result in higher channel catfish survival and a greater return on investment.

Several potential sources of mortality have been identified for stocked sport fish. Initial mortality may result from stress induced by rapid temperature change (Mather and Wahl 1989) or hauling and handling (Carmichael et al. 1984). Predation from resident piscivores, such as largemouth bass Micropterus salmoides, can adversely affect survival of stocked fish (Stein et al. 1981; Wahl and Stein 1989; Santucci and Wahl 1993) and has been suggested to be important in regulating survival of channel catfish (Krummrich and Heidinger 1973; Spinelli et al. 1985; Storck and Newman 1988). Vulnerability of stocked fish to largemouth bass appears to be related to size at stocking (Storck and Newman 1988; Santucci and Wahl 1993), predator population demographics (Mestl 1983; Carline et al. 1986), and availability of alternate prey (Spinelli et al. 1985). Although not specific to stocked fish, additional sources of mortality may include hooking mortality of angler-released fish (Wydoski 1977) and spillway escapement (Walburg 1971). We evaluated the influence of these factors on harvest of 200- and 250-mm channel catfish stocked in an impoundment containing an established centrarchid community. In addition, we used size-specific production costs as well as angler catch and harvest data to determine the most economical size for stocking.

Study Area

Ridge Lake, Illinois (39° 27' N, 80° 09' W) is a 5.6-hectare experimental fishing lake with a maximum depth of 6.5 m and mean depth of 2.8 m. Typically, the lake is thermally stratified at a depth of 1-3 m during late May through early September; temperature in the epilimnion ranges from 19 to 33°C and the hypolimnion is anoxic. Mean summer Secchi depths are less than 1 m and moderate standing crops of submersed macrophytes exist in the shallow regions. The primary overflow structure, a tower spillway, discharges water from the lake bottom and can also be used to drain the lake. When the capacity of the tower spillway (0.71 m^3/s) is exceeded, water is discharged over an auxiliary surface spillway. Both spillways are equipped with downstream weirs (13-mm mesh wire screen) designed to hold emigrating fish alive in catch baskets.

Methods

Ridge Lake was drained in October 1985 and restocked during 1986 with juvenile and adult largemouth bass (27 kg/hectare), bluegills Lepomis macrochirus (15 kg/hectare), and black crappies Pomoxis nigromaculatus (5 kg/hectare) obtained from area lakes and fish hatcheries. Age-0 walleyes Stizostedion vitreum (4 kg/hectare) were stocked annually from 1987-1989. Age-1 channel catfish from Illinois Department of Conservation fish hatcheries were stocked from July to September, 1986-1989. Before stocking, fish were graded into two size groups and a subsample from each group was measured (total length, nearest mm) and weighed (nearest g). Individuals from the 200- and 250-mm groups were marked in each year with unique fin clips (right and left pelvic, respectively) that remained detectable throughout the study. In alternate years, the adipose fin was removed from all fish stocked to distinguish year classes. Differences in availability of fish from the hatcheries resulted in channel catfish from both size groups being stocked concurrently in 2 years and at different times in two others (Table 1). Equal numbers of each size class of channel catfish were stocked each year, and within size groups, mean lengths were similar among years.

Stocking mortality of channel catfish was estimated by holding subsamples of fish ($N \geq 30$) in suspended cylindrical cages (1.2 m deep x 1.0 m diameter consisting of 6.4-mm mesh plastic screening; N = 3 per stocking). Cages extended below the lake surface to depths of 1.0 m. Mortality in cages was used to estimate losses associated with hauling, handling, fin clipping and temperature stress. Numbers of dead and live fish were counted after 24 h and live fish were released in the lake.

To evaluate the importance of predation, we examined stomach contents of largemouth bass on the day of stocking and up to six additional days during the week following stocking; if predation was to occur, it would likely be highest during this time (Wahl and Stein 1989). Other predators were not examined because none were large enough to eat channel catfish of the sizes stocked. Largemouth bass were collected by electrofishing with a three-phase AC boat shocker (3,000 W, 230 V) and stomach contents were removed with clear acrylic tubes (Van Den Avyle and Roussel 1980).

To determine predator abundance, we estimated the population size of largemouth bass capable of ingesting stocked channel catfish in September and October of each year. Fish were captured for marking by electrofishing and were recaptured within 1 month by electrofishing and angling. An upper caudal fin clip was used to mark fish and population size was estimated with the Chapman modification of the Petersen formula (Ricker 1975). The minimum total length (TL, mm) of largemouth bass (LMB) included in the population estimates was determined from empirical estimates of the maximum size of channel catfish (CCF) that could be eaten by various sizes of largemouth bass (Mestl 1983):

$$\text{TL LMB} = 23.596 + (1.515 \times \text{TL CCF}).$$

Maximum throat diameters of largemouth bass and maximum body widths of channel catfish as a function of total length were used to develop this relationship.

A complete creel census measuring total angler effort, catch, and harvest was conducted while the lake was open to public fishing, late April through mid-October 1987-1991; the lake was closed to fishing in 1986. In addition to providing angling statistics, this census allowed us to assess hooking mortality and angler exploitation of channel catfish and supplement electrofishing samples for largemouth bass population estimates and diets. We were able to use angler-caught fish to supplement samples because estimates of size structure and diet composition are similar for largemouth bass sampled by electrofishing and angling (Santucci and Wahl 1991). Fishing access was through a single entry point and only boat fishing was allowed. A minimum length limit for largemouth bass of 357 mm was enforced; there were no length or bag restrictions for channel catfish. Before fishing, anglers were instructed to keep all boated fish in live wells. Fish were retrieved at a lake-side laboratory where they were measured for length and weight, and checked for fin clips. Unwanted channel catfish were held overnight (12-20 h) in a floating creel (see previous description of cages) to determine hooking mortality, after which survivors were returned to the lake.

We monitored spillway escapement of channel catfish daily when water discharged over either the tower or the surface spillway. Weir catch baskets were checked daily to avoid losses of retained fish to mammalian or avian predators; we saw no signs that predators were feeding at either spillway weir. Channel catfish found in weirs were discarded after they were measured for length and checked for fin clips.

To assess which channel catfish size group was the most economical to stock, we used initial costs per individual and numbers stocked to determine the total cost for each stocking. Initial costs were interpolated from cost estimates of commercial producers for various sized channel catfish in the east-central region of the United States (American Fisheries Society 1992). These cost estimates included both direct and indirect costs of rearing. Dividing the total cost by the numbers of fish caught and harvested after a minimum of 3 full angling seasons provided costs per caught and costs per harvested channel catfish.

To estimate growth rates, we sampled channel catfish annually in September and October 1986-1989 with electrofishing gear (effort = 4 h), gill nets (7.7- x 1.8-m panels of 19-, 25-, 32-, 38-, 45-, and 51-mm bar mesh; 33 net-days), trot lines (20 hooks/line; effort = 58 line-days), and wooden slat traps (132 trap-days). Multiple gears were used to avoid potential size selective bias of individual gears (Santucci and Wahl 1990). Fish collected in fall samples were measured for length and weight. Despite extensive sampling, we failed to collect enough channel catfish to evaluate survival by either catch-per-unit-effort or mark-recapture population estimates. Thus, we used harvest data to evaluate overall channel catfish survival. Except where indicated, statistical analyses were one-way analysis of variance for randomized complete block designs (blocked by year). An arcsine transformation was used on percentage data before statistical tests were conducted (Steel and Torrie 1980).

Results

Stocking 250-mm channel catfish did not consistently increase catch or harvest above that of 200-mm fish. Harvest was high for both size groups; 52 to 76% of the 200-mm fish and 72 to 92% of 250-mm fish were harvested (Table 2). Comparing across all years, we found no differences between size groups in mean number caught ($\underline{N}$ = 365 for 200 mm and 392 for 250 mm; ANOVA, $\underline{P} > 0.50$), mean number harvested (66% for 200 mm and 83% for 250 mm; $\underline{P} = 0.35$), or mean total weight harvested (116 kg for 200 mm and 164 kg for 250 mm; $\underline{P} = 0.23$).

Non-angling mortality of channel catfish was low. Although lake temperatures on stocking days were high (24 - 32°C), no fish died as a result of stress associated with stocking (Table 2). Predation by largemouth bass on stocked channel catfish also was low; only one individual from the 200-mm groups and none from the larger size groups were eaten by largemouth bass ($\underline{N}$ = 457) examined during the week after each stocking. Predation mortality was low for both size groups even though densities of largemouth bass capable of eating them were higher for fish stocked at 200-mm (mean predator density ±95% confidence intervals = 26±21 fish/hectare) than at 250 mm (2±1 fish/hectare; $\underline{P} = 0.04$). Hooking mortality of channel catfish released in cages was low for all sizes of fish (<8%, $\underline{N}$ = 1,158) despite extensive handling and prior holding in boat live wells. As a source of losses of stocked fish, hooking mortality did not differ between size groups (1.9% for 200 mm and 1.8% for 250 mm ; $\underline{P} > 0.50$; Table 2). Like other measured sources of mortality, emigration was low and did not differ between size groups (2.0% for 200 mm and 1.8% for 250 mm; $\underline{P} = 0.49$).

We observed similar growth rates of both channel catfish size groups in Ridge Lake. The mean annual length increment (±1 SE) for the 200- and 250-mm groups from the 1986-1988 stockings was 107±25 and 111±14 mm, respectively, the year after stocking and 50±9 and 41±11 mm the following year. Although growth rates were similar, differences in stocking date among years influenced the length relationship between size groups. Mean lengths of both size groups differed in fall after stocking and in each subsequent year when stocked concurrently as in 1986 (t-test, $\underline{P} < 0.02$; Figure 1) and 1989 ($\underline{P} < 0.001$; mean lengths ±95% confidence intervals = 251±10 and 298±9 mm for 200- and 250-mm channel catfish, respectively). However, when the smaller size groups were stocked 3 and 8 weeks before the larger fish as in 1987 and 1988, respectively, mean lengths were either similar by fall of the stocking year (1987; $\underline{P} = 0.06$) or the 200-mm fish were larger than the 250-mm fish (1988; $\underline{P} = 0.01$). For these stockings, channel catfish from both size groups were similar in size after the stocking year (Figure 1).

Exploitation of channel catfish by anglers was high during the study. In five fishing seasons, the total catch was 101% and harvest 74% for all fish stocked in 1986-1988. High exploitation occurred with high annual fishing pressure (mean = 898 angler-h/hectare) and moderate effort directed at channel catfish (115 angler-h/hectare). Mean annual harvest did not differ between size groups (two-way ANOVA, $\underline{P} = 0.47$). However, for both size groups, harvest differed in successive years after stocking ($\underline{P} = 0.002$; Figure 2). During the year of stocking, fewer than 5% of stocked fish were harvested because angler catches were low in most years (<16% of the numbers stocked except in 1989 when 32% were caught) and most anglers voluntarily released small fish. Anglers released 73% of their catch of newly stocked fish (mean length = 268 mm, mean weight = 157 g) compared to 26% in years after stocking (mean length > 330 mm, mean weight > 320 g). In the 2 years after the stocking year, anglers harvested 60% of stocked channel catfish, after which harvest was low because few fish remained in the lake (Figure 2).

Estimated rearing costs of the larger channel catfish were about 1.3-times those of the smaller size groups (Table 3). Because exploitation was high, costs per caught and harvested channel catfish (US$0.46-0.65 and 0.71-0.98 per individual, respectively) were low for all stockings. However, costs per individual harvested were lower for the 200-mm than the 250-mm size groups in 2 of 3 years (Table 3). Likewise, cost per individual caught by anglers was lower for the 200-mm fish in 2 of 3 years. For all years combined, the net economic return was similar for 200- and 250-mm fish.

Discussion

For 75- to 200-mm channel catfish, increased size at stocking can improve survival in lakes with established piscivore populations (Crance and McBay 1966; Dudash 1987; Storck and Newman 1988). Because survival increased for channel catfish up to 200 mm, we expected that further gains in survival might be achieved by stocking larger fish. However, we were unable to show higher harvest of fish stocked at 250 mm. Furthermore, our assessment of measurable sources of mortality did not indicate changes in stocking protocols that might result in increased survival of the larger fingerlings.

As has been documented for various other sport fish species (Wahl and Stein 1989; Santucci and Wahl 1993), predation by largemouth bass may be one of the most important sources of mortality of stocked channel catfish. Several authors have shown that either survival or harvest of channel catfish was related inversely to the density of predators large enough to prey on stocked fingerlings (Crance and McBay 1966; Mestl 1983; Storck and Newman 1988). We observed low predation losses for both size groups stocked in Ridge Lake even though effective predator densities were higher for the smaller fingerlings than for the larger ones. The density of largemouth bass capable of eating 200-mm fish (26/hectare) may have been low enough that extensive losses to predation were avoided. Our estimates of effective predator densities were probably liberal because they were based on maximum sizes of channel catfish that largemouth bass could physically ingest. Previous work has shown that largemouth bass typically eat smaller fish than those approaching maximum throat dimensions (Lawrence 1958; Keith and Barkley 1971). As shown for other stocked species, predation mortality may be higher in waters with higher densities of large predators (Carline et al. 1986) or where alternate forage is lacking (Spinelli et al. 1985).

Factors other than predation could influence survival of stocked channel catfish. Whereas other studies have demonstrated substantial spillway escapement of stocked sport fish (Groen and Schroeder 1978; Willis and Stephen 1987), channel catfish escapement was insignificant during our study even though Ridge Lake has a high watershed to lake surface area ratio (66:1). Likewise, escapement losses of 200-mm channel catfish fingerlings were 0-9% in an earlier study at Ridge Lake (Storck and Newman 1988), but were as high as 22% for smaller fingerlings (90-130 mm). Small channel catfish can also be abundant in the discharge of large reservoirs (Walburg 1971). Whereas escapement losses may depend on spillway design and discharge rates, they may be lower for larger channel catfish. Similarly, our results suggest losses of large channel catfish fingerlings due to stocking stressors probably will be low. Substantial mortality associated with hauling, handling, and thermal stress has been documented for largemouth bass (Carmichael et al. 1984), esocids (Mather and Wahl 1989), walleyes (Santucci and Wahl 1993), and freshwater drum Aplodinotus grunniens (Johnson and Metcalf 1982). In contrast, we consistently observed no stocking losses of channel catfish that were handled extensively, fin clipped, transported, and stocked at high water temperatures.

We hypothesized that hooking mortality would be high for channel catfish released by anglers because fish caught with natural baits, those typically used for channel catfish, usually experience higher mortality than fish caught with artificial lures (Wydoski 1977; Payer et al. 1989; Santucci and Wahl 1993). Despite almost exclusive use of natural baits for channel catfish, hooking mortality was low for all sizes of fish released. In waters where natural mortality is also low and growth and exploitation are high, the implementation of protective size limits could possibly increase the total weight and mean size of catfish harvested.

Channel catfish growth and stocking date appeared to influence angler exploitation. Fish from both size groups grew rapidly in Ridge Lake compared to populations from other midwestern reservoirs (Marzolf 1957; Stevenson and Day 1986) and small impoundments (Davis 1959). In years that smaller fingerlings were available for stocking earlier than larger ones, anglers harvested similar numbers of fish from each size group. Rapid growth of small fingerlings in the lake resulted in both size groups being similar in size by fall of the stocking year, and thus equally vulnerable to harvest by anglers in subsequent years. In contrast, when stocked concurrently, both size groups maintained differences in size over time and anglers harvested fewer fish from the small size group. Lower overall harvest may have resulted because, before reaching harvestable size, the small size group was susceptible to natural losses longer than the large size group. Regardless, concurrent stocking of both size groups is not typical given that smaller channel catfish generally would be available from hatcheries earlier in the year than larger ones. With typical stocking times relative to each size group, numerical harvest in lakes with rapidly growing channel catfish should be similar for either 200- or 250-mm fingerlings. However, in impoundments where growth of channel catfish is slow, stocking larger fish may reduce the time necessary to reach harvestable size (Baur et al. 1976).

Angler exploitation had a far greater effect on channel catfish survival than any other potential source of mortality. Total exploitation in Ridge Lake was high, but similar to other midwestern impoundments receiving moderate fishing pressure (Eder and McDannold 1987). Combining all measured sources of mortality, we were able to account for 78% of stocked fish. However, there was variability in survival among stockings that was not explained. Some percentage of fish from each stocking remaining in the lake and unmeasured contributors to mortality, such as condition and health at stocking (Belusz 1978), parasites, starvation, or long-term effects related to stocking stress or hooking, may partially explain the observed variability in survival.

Management Implications

Our results suggest that managers can expect high survival and angler returns of channel catfish fingerlings ≥200 mm when they are stocked in small impoundments with established fish populations. By stocking these large fingerlings, we were able to minimize losses to largemouth bass predation, suggested as important for smaller sizes of channel catfish (Krummrich and Heidinger 1973; Mestl 1983; Storck and Newman 1988). We found other sources of mortality as well as angler catch and angler harvest were all similar between 200- and 250-mm fish. In addition, return on investment was similar for both size groups. Because 250-mm fish did not have a higher economic return or contribute substantially more to the fishery than the smaller size group, stocking fingerlings larger than 200 mm appears unnecessary for most put-grow-and-take fisheries. Stocking 200-mm channel catfish instead of larger ones should also decrease rearing costs for production facilities, particularly if fingerlings were harvested as soon as they reached a length of 200 mm. However, rearing and stocking larger fish may be beneficial in lakes with an abundance of large predators or where channel catfish growth is slow.

Additional efforts to manage channel catfish in small impoundments should focus on optimizing yield by regulating angler exploitation. With no angling restrictions, we found that large channel catfish fingerlings were most vulnerable to harvest the first and second years after stocking. Few fish were harvested the year they were stocked; however, high catches in one year and the willingness of some anglers in all years to harvest small channel catfish indicate the potential for high harvest of newly stocked fish. High exploitation rates and low hooking mortality of all sizes of fish suggest that protective size limits may be useful in deferring fishing mortality, thus increasing the size of fish available for harvest without substantially reducing numerical harvest. However, because a reduction in fishing mortality may lead to an increase in natural mortality and a lower yield, further studies are needed to determine the specific effects of harvest restrictions on stocked channel catfish populations. If length limits are deemed necessary, angler preferences for channel catfish as food rather than as a trophy (Eder and McDannold 1987) should be considered in determining what size restriction to enforce. Regardless of the size restriction, growth should be monitored when length limits are implemented because, as has been shown with other species (Rasmussen and Michaelson 1974; Serns 1978), growth may slow as densities of sublegal fish increase. Adjustments in stocking rates or alternate year stocking may be necessary in lakes where growth is typically slow or has been reduced after enforcement of minimum length limits.

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Table 1. Stocking dates, mean total lengths ($\underline{N} \geq 30$), weights, and 95% confidence intervals for two size groups of channel catfish stocked in Ridge Lake, Illinois, 1986-1989. The annual stocking rate was 67 fish/hectare for each size group.

Year	Stocking date	Mean length (mm)	Mean weight (g)
1986	22 Aug	192±2.5	47±4.3
	22 Aug	253±2.1	149±5.3
1987	18 Aug	197±3.0	58±5.6
	11 Sep	248±5.2	147±21.0
1988	12 Jul	205±2.5	80
	13 Sep	251±3.4	147
1989	24 Jul	202±2.4	69±2.9
	24 Jul	249±2.7	150±5.1

Table 2. Estimated losses of two length groups of channel catfish from various sources after stocking in Ridge Lake, Illinois, 1986-1989. Angler harvest and mortality estimates represent percentages of the number stocked. Angler harvest was determined from a creel census conducted annually during 1987-1991; the lake was closed to fishing in 1986. Stocking mortality was not assessed (NA) in 1986. No largemouth bass sampled in 1987 were large enough to eat channel catfish from the 250-mm length group. Angler harvest is presented only for stockings fished a minimum of three full seasons.

				Sources of mortality			
Year stocked	Length group (mm)	Fishing seasons	Angler harvest	Stocking mortality	Largemouth bass predation	Hooking mortality	Spillway escapement
1986	200	5.0	52	NA	0.0	2.1	0.8
	250	5.0	92	NA	0.0	1.1	0.3
1987	200	4.5	70	0.0	0.3	1.6	1.1
	250	4.5	85	0.0	---	1.1	0.8
1988	200	3.5	76	0.0	0.0	1.9	2.7
	250	3.5	72	0.0	0.0	1.1	3.2
1989	200	2.5	---	0.0	0.0	2.1	4.0
	250	2.5	---	0.0	0.0	4.0	2.9
Mean	200	3.9	66	0.0	0.1	1.9	2.2
	250	3.9	83	0.0	0.0	1.8	1.8

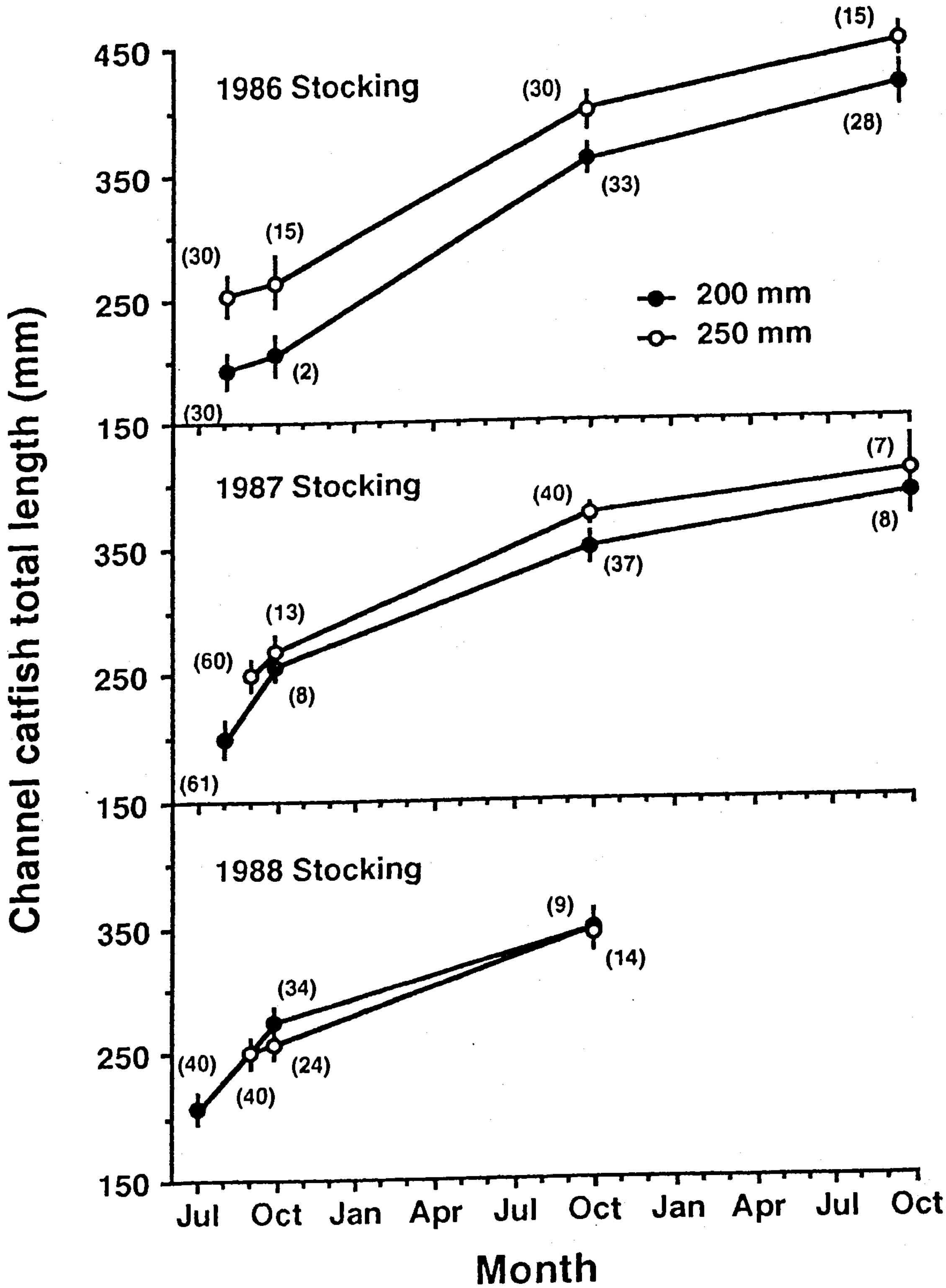
Table 3. Cost (US$) per individual harvested by anglers for two sizes of channel catfish stocked in Ridge Lake, Illinois, 1986-1988. Costs per individual for each stocking were interpolated from cost estimates of commercial producers for various sized channel catfish in the east-central region of the United States (American Fisheries Society 1992).

Year	Cost per individual stocked		Number caught		Number harvested		Cost per channel catfish caught		Cost per channel catfish harvested	
stocked	200 mm	250 mm	200 mm	250 mm	200 mm	250 mm	200 mm	250 mm	200 mm	250 mm
1986	0.51	0.67	300	392	194	345	0.64	0.64	0.98	0.73
1987	0.52	0.66	354	379	264	320	0.55	0.63	0.74	0.77
1988	0.54	0.66	440	405	285	269	0.46	0.61	0.71	0.93
Mean	0.52	0.66	365	392	248	311	0.55	0.63	0.79	0.80

Figure Captions

Figure 1. Mean total lengths for two size groups of channel catfish stocked in Ridge Lake, Illinois, 1986-1988. Channel catfish were measured at stocking (July-September) and were sampled each October 1986-1989 with electrofishing gear, gill nets, trot lines, and slat traps. Sample sizes are in parentheses; vertical lines represent 95% confidence intervals. Data from October 1989 are not presented for the 1986 stocking because sample size was small (<5 fish).

Figure 2. Mean annual angler harvest for two size groups of channel catfish stocked in Ridge Lake, Illinois, 1986-1988. Angler harvest was determined from a creel census conducted annually during 1987-1991; the lake was closed to fishing in 1986. Sample sizes in parentheses are number of stockings and, for each year after stocking, are similar for both size groups; vertical lines represent 1 SE.



Channel catfish total length (mm)
Month
1986 Stocking
1987 Stocking
1988 Stocking
200 mm
250 mm
450
350
250
150
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
(15)
(30)
(28)
(33)
(15)
(30)
(2)
(30)
(7)
(40)
(8)
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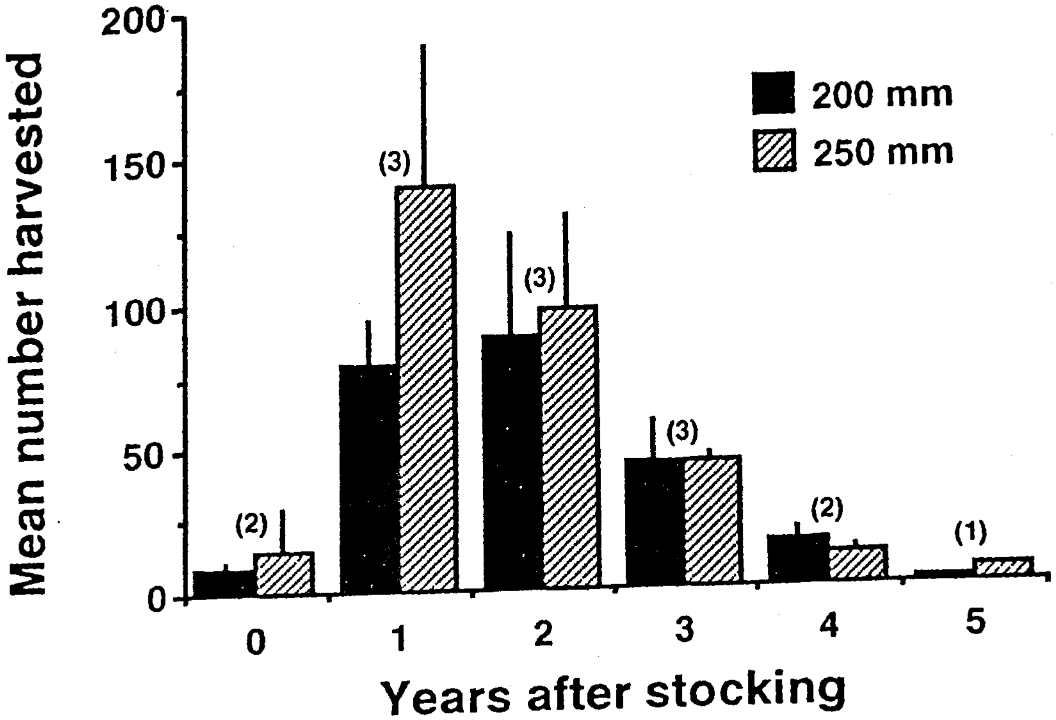

200 mm
250 mm
(2)
(3)
(3)
(3)
(2)
(1)
0
50
100
150
200
Mean number harvested
0
1
2
3
4
5
Years after stocking

APPENDIX C

Effects of gizzard shad on centrarchid and walleye populations

David F. Clapp[1]

Illinois Natural History Survey

Center for Aquatic Ecology

Ridge Lake Field Station

R. R. 1, Box 233

Charleston, IL 61920

and

David H. Wahl

Illinois Natural History Survey

Center for Aquatic Ecology

Kaskaskia Biological Station

R. R. 1, Box 157

Sullivan, IL 61951

1 - Present address: Michigan Department of Natural Resources, 96 Grant Street, Charlevoix, Michigan 49720, USA.

Abstract. - Forage fish introductions, in particular clupeid introductions, have been used in attempts to improve sport fish populations. The effects of gizzard shad *Dorosoma cepedianum* introductions are likely to be complex, and the mechanisms underlying these relationships are not well understood. We evaluated the effects of a gizzard shad introduction on predator (walleye *Stizostedion vitreum* and largemouth bass *Micropterus salmoides*) and forage fish (bluegill *Lepomis macrochirus*) populations by measuring diet, growth, and survival in Ridge Lake, Illinois for three years prior to and five years following introduction. Significant declines in density of zooplankton, larval bluegill, and young-of-year bluegill coincided with gizzard shad becoming the dominant larval fish in the lake. Juvenile largemouth bass density increased slightly (from 40 to 60 fish/m2) following shad introduction, but average total length declined from >80 mm to 60 mm. Gizzard shad became an important part of the diet of adult largemouth bass (36% by volume) and walleye (85%). While we saw major changes in diet of both adult walleye and adult largemouth bass, the changes were not reflected in early adult growth of either predator and survival of walleye and abundance of largemouth bass declined significantly following the introduction of gizzard shad to Ridge Lake. The effects of introducing gizzard shad may be positive or negative, depending on the target species and population attribute of interest. Introduction of any forage fish to improve sport fish populations should be undertaken only with caution and after careful consideration of management objectives.

Forage fish of the appropriate size and type are important to the survival and growth of predators such as largemouth bass *Micropterus salmoides* and walleye *Stizostedion vitreum*. Forage fish introductions, especially gizzard shad *Dorosoma cepedianum* or threadfin shad *Dorosoma pretense*, have been used for some time in attempts to improve growth and survival of sport fish (Noble 1981, DeVries and Stein 1990). Clupeid introductions have tended to enhance predator populations (DeVries and Stein 1990), but results have been inconsistent. While they are used frequently, the effects of forage introductions are likely to be complex (DeVries and Stein 1992), involving both direct and indirect interactions. Few studies have adequately addressed these potential interactions because they are complex and have potential positive and negative effects at many trophic levels.

An obvious impact of the introduction of forage fish would be major shifts in the diets of predator species. However, forage use may vary with predator size, and with time of year. Additionally, timing of forage spawning and growth rates have the potential to significantly impact their use by predators. By causing changes in diet, introduction of alternative forage species can ultimately alter growth patterns. Beyerle (1978) and Schneider (1975, 1979) found that walleye grew more slowly with bluegill *Lepomis macrochirus* than when minnow forage were available. Presence of gizzard shad may improve largemouth bass growth rates because they are easier to catch and digest than other prey items, such as bluegill (Wahl and Stein 1988). Larval gizzard shad may serve as forage for young-of-year largemouth bass, and the presence of this additional forage may lead to increased growth rates and thus increased over-winter survival for these young bass (Adams et al. 1982).

In addition to increasing diet diversity and improving growth rates, another potential positive effect of forage species may be to improve survival of fish at higher trophic levels. Walleye recruitment has been linked to early growth, over-winter survival, and food availability (Madenjian et al. 1991, Schneider 1979). Largemouth bass predation can at times be an important source of explained mortality for stocked walleye (Santucci and Wahl 1993), and alternate prey in the form of gizzard shad may lead to decreases in predation on stocked walleye (Forney 1976). Reduced predation may also increase survival of young-of-year (YOY) centrarchids.

There are also potential negative effects of the presence of gizzard shad. Introduction of gizzard shad may result in competition among larval fish and possible resource depletion (Dettmers and Stein 1992). Temporal and spatial availability of zooplankton can have profound effects on growth of juvenile fish and subsequent recruitment (Miller et al. 1990); by competing for zooplankton, introduced forage fish may negatively affect growth and recruitment of the same predator populations they were intended to enhance (DeVries and Stein 1990, DeVries et al. 1991). In addition to directly affecting sport fish growth and survival in early life history stages by competing for zooplankton, introduced forage may indirectly effect predators by influencing growth and survival of their prey (DeVries et al. 1991). Forage introductions may reduce growth and recruitment of forage species such as bluegill. Competitive influences may be particularly intense on bluegill populations, since, like gizzard shad, they depend on zooplankton during the majority of their larval and juvenile life history. Gizzard shad generally spawn earlier in the year than bluegill and because they are so prolific, have the potential to severely limit zooplankton resources for bluegill.

Finally, introduced forage may influence zooplankton populations and thus water clarity. According to the concept of cascading trophic interactions (Carpenter et al. 1985), as vertebrate zooplanktivory increases -- i.e., gizzard shad introduction -- small zooplankters may come to dominate a lake's herbivore assemblage and chlorophyll-a concentration in the lake may increase. The potential for each of these interactions may depend upon position along the trophic gradient (Post and McQueen 1987) and even upon the type of zooplankton predator introduced (Vanni and Findlay 1990).

The accidental introduction of gizzard shad into a research reservoir in Illinois provided us with an opportunity to study in detail the relationships between introduced forage and resident forage and predators. Specifically, we wanted to examine the potential for this forage fish manipulation to influence survival and recruitment of stocked walleye and resident centrarchids in a small (six hectare) impoundment with a forage base previously dominated by bluegill. Because of the extensive sampling conducted in Ridge Lake prior to the introduction of gizzard shad, we had sufficient pre-manipulation data with which to evaluate the effect of gizzard shad introduction. Our objectives were first, to evaluate changes to bluegill, largemouth bass, and walleye diet, growth, and survival following the introduction of gizzard shad, and secondly, to relate these changes to management of fish populations in small impoundment systems. Information concerning predator-prey relationships in small impoundments will help determine the likelihood for success of forage fish introductions in these waters.

Methods

Study area and fish populations. - Ridge Lake is an Illinois Natural History Survey (INHS) research lake in Coles County, Illinois, that was constructed in 1941 by impounding Dry Run Creek. The lake has a surface area of 5.6 hectares, an average depth of 2.8 m, and a maximum depth of 6.5 m. Two lake spillway systems (tower and surface) are both equipped with weirs (constructed of 13 mm-mesh galvanized wire screen) designed to retain fish during discharge events.

Ridge Lake was drained in October 1985 and restocked during 1986 with largemouth bass, bluegill, black crappie *Pomoxis nigromaculatus*, and channel catfish *Ictalurus punctatus* in numbers and sizes to approximate the biomass and size structure of mature populations of similar-sized impoundments in Illinois (Table 1). Walleye and additional channel catfish were stocked each year from 1987 through 1994 (Table 1). Survival of fry and small fingerlings was poor at Ridge Lake; few fish from these size classes were collected in seven years of sampling. Data on walleye presented in this paper are based only on stockings of large (5-8") fingerling walleye. Adult gizzard shad were accidently introduced into Ridge Lake from an upstream impoundment in late fall 1989, and these fish successfully reproduced during 1990-1994.

Water quality and zooplankton. - Secchi disc measurements, temperature profiles, and dissolved oxygen profiles were taken at 3 sites in Ridge Lake bi-weekly from April to October in each year of the study.

We monitored zooplankton abundance between April and August in 1989-1994. Vertical zooplankton tows were made bi-weekly at the same time water quality samples were collected. Zooplankton samples were collected at three locations on Ridge Lake using a 0.5 m diameter, 64 μm mesh zooplankton net and preserved in a sucrose-10% formalin solution. Zooplankton samples were processed as described in Dettmers and Stein (1992) and Welker et al. (1994). Samples were adjusted to a constant volume and subsampled by 1 ml (1/100) aliquot. Zooplankton were identified and counted by major group (Daphnids, other Cladocerans, calanoid Copepods, cyclopoid Copepods, Nauplii, and Rotifers), and subsamples of each group (N=30 individuals per group) were measured (total body length, 0.01 mm).

Larval fish. - We monitored larval fish abundance, growth and survival in Ridge Lake between May and August in 1987-1994. Replicate ichthyoplankton tows were conducted weekly (within 30 min of sunset) using Miller high-speed ichthyoplankton samplers. Tows sampled the water column at the surface, 1, 2, and 3 m depth contours. All larval fish collected were identified and measured (TL, nearest mm). Relative abundance (density, fish/m3) was determined as the number of fish collected divided by the volume of water sampled. Relative annual production was estimated by summing average weekly density estimates. Otoliths were extracted from a subsample of larval bluegill on each sampling date to determine age (swim-up date), growth, and mortality rates.

Larval fish growth (mm/d) was measured by subtracting size at first feeding (5 mm; Auer 1982) from size at capture and dividing by age (Rice et al. 1987). Saggital otoliths were removed from a subsample of fish on each collection date and analyzed according to methods described in Welker et al. (1994) and Davis et al. (1985). Monthly average growth rates were calculated for fish collected in May-August in years prior to and following gizzard shad introduction to Ridge Lake. Only larval bluegill ≤11 mm were included in this analysis, since bluegill >11 mm exhibited significant avoidance of our sampling gear.

Larval bluegill mortality rates were determined following the otolith increment frequency method (Essig and Cole 1986, Zigler and Jennings 1993). Otolith analysis was conducted as described above for growth determination; only larval bluegill from 5-11 mm total length were used in estimating mortality rates. Mortality was calculated for early- (May-June) and late- (July-August) collected larval bluegill. Mortality estimates for each collection period, year, and for pre- and post-gizzard shad introduction periods were compared by testing for equality of regression coefficients (Zar 1974).

Juvenile fish. - Relative abundance and growth of young-of-year bluegill and largemouth bass was determined from fall block-net sampling (Bayley and Austen 1990). Shoreline block-net samples (N=3, 0.01 hectare each) were conducted in September of each year (1987-1994). Marked fish were placed in nets prior to application of rotenone to estimate efficiency of recovery efforts. Fish were collected for approximately 1 h, after which time the block net was pulled and any remaining fish were collected. Otoliths were collected from a subsample of bluegill to separate age 0 from age 1 and older fish; all fish collected in block nets were measured (TL). Density of juvenile bluegill and largemouth bass in littoral areas of Ridge Lake was determined by dividing the number of each age class of each species collected by the ratio of fish recovered to marked fish placed in the net for that age class. Average density was calculated as the arithmetic mean of the three nets fished in each year.

Young-of-year gizzard shad were collected during bi-weekly electrofishing samples between August and December in 1990-1994. Catch-per-unit-effort (CPUE) was determined for each year, and shad were measured (TL) to determine the availability for walleye and centrarchid predators.

Adult fish. - Diet, growth, and survival or relative abundance of stocked walleye and resident centrarchids (bluegill and largemouth bass) were assessed from bi-weekly electrofishing samples, fall trapnetting and gillnetting, and a complete creel census. During each sampling period, stomach contents of walleye and largemouth bass were removed through the use of clear acrylic tubes (Van Den Avyle and Roussel 1980). Numbers of walleye in bass stomachs were combined with largemouth bass population estimates (see below) to determine the total losses of stocked walleye to largemouth bass predation. Total length and weight data were collected from all walleye, largemouth bass, and bluegill collected. A representative sample of all species was aged (using scales or otoliths) to estimate growth.

Fall abundance of largemouth bass and walleye was determined using Peterson (1987-1990) or Schnabel (1991-1994) mark-recapture population estimates. Relative abundance or year class strength of bluegill was determined as catch-per-unit-effort (CPUE) during fall (September-October) electrofishing surveys. Data collected from a complete creel census was used to evaluate catch and harvest of walleye, channel catfish, largemouth bass, bluegill, and black crappie.

Data analysis. - Data were assigned pre- and post- gizzard shad introduction periods. Pre-introduction years were 1987-1989 and post-introduction years were 1992-1994. The years 1990 and 1991 were considered to be transition years, when gizzard shad were becoming established in the lake, and were not included in the analyses. Data collected prior to introduction of gizzard shad into Ridge Lake was compared with post-introduction data to evaluate potential impacts of gizzard shad introduction.

Because secchi disc depth, zooplankton abundance and size structure, and juvenile bluegill and largemouth bass abundance and growth data were collected from fixed stations through time, pre- and post-gizzard shad introduction comparisons for this data were made using a repeated-measures split plot analysis of variance design (RMSP ANOVA; Maceina et al. 1994). Composition of the diet of adult walleye and largemouth bass prior to and following the introduction of gizzard shad were compared using the likelihood ratio chi-square test (SAS Institute 1988). Other comparisons (abundance and growth of juvenile gizzard shad, larval bluegill, and all adult fish) were made by analysis of variance (ANOVA) using the general linear models (GLM) procedure (SAS Institute Inc. 1988). Multiple comparisons were made by Tukey's studentized range test or least-squares means. The significance level for all tests was $P < 0.05$; probabilities for least-squares means comparisons were adjusted using the Bonferroni procedure.

Results

Zooplankton and water quality

Secchi disc depth declined significantly following the introduction of gizzard shad to Ridge Lake, suggesting an increase in phytoplankton abundance. Average secchi disc depth in May prior (1987-89) to gizzard shad introduction was 2.4 m. Secchi disc depth declined to 0.8 m in years (1992-94) following gizzard shad introduction.

During this same time period, total zooplankton density declined from >1,000 organisms/L to <500/L (Figure 1). While we saw only small differences in total zooplankton density early in the year (April and May), we observed large differences in cladoceran and copepod density at this time (Figure 2). Cladoceran density declined from >200 to <25/L, while copepod density declined from almost 300/L to <50/L (Figure 2). While we saw an average monthly decline in large zooplankton of 40-60%, we observed concurrent increases in average monthly rotifer density of greater than 100% throughout the year (Figure 2).

The size structure of the zooplankton population in Ridge Lake also changed following the introduction of gizzard shad, but the effect varied depending on zooplankton type. Average body length of daphnids and cyclopoid copepods declined, where as length of other cladocerans and rotifers increased (Table 2). Calanoid copepod and nauplii length did not change significantly.

Larval fish

Prior to the introduction of gizzard shad to Ridge Lake, larval bluegill densities ranged from 25-160 fish/m^3 (Figure 3). The peak larval bluegill density usually occurred in early June, with a second peak sometimes occurring later in June or in early July. Larval bluegill were collected from early May through mid-August.

Gizzard shad first spawned in Ridge Lake in 1990, and quickly became the dominant ichthyoplankton. Peak larval gizzard shad density

(25-40 fish/m^3) usually occurred in late May or early June, and larval shad were collected from early May through late June (Figure 3). We observed significant declines in larval bluegill density following the introduction of gizzard shad to Ridge Lake. Peak density decreased from 160 to <10 fish/m^3 (Figure 3). In addition, larval bluegill were not as abundant later in the summer as they were in pre-gizzard shad years.

Concurrently with the decline in abundance of larval bluegill, we observed a decline in growth of larval bluegill (Figure 4). A significant decline in growth from 0.32 mm/d to 0.23 mm/d was observed in May, coincident with the major impacts on large bodied zooplankton. In June and later months, we saw no difference in growth of larval bluegill pre- and post-shad introduction (Figure 4).

Juvenile fish

Following the introduction of gizzard shad to Ridge Lake, we observed significant declines in age-0 bluegill density, parallel to changes in larval bluegill density, but no significant change in age-0 largemouth bass density (Figure 6). Average abundance of juvenile bluegill, as measured in fall block net samples, declined from almost 70 fish/m^2 prior to the introduction of gizzard shad to 20 fish/m^2 following the introduction of gizzard shad to Ridge Lake (Figure 6). Age-0 largemouth bass density increased from approximately 40 to 60 fish/m^2 (Figure 6).

We also observed increases in average total length of bluegill but significant declines in fall total length of largemouth bass (Figure 6). Average bluegill total length was 26 and 34 mm pre- and post-gizzard shad introduction, respectively, while age-0 largemouth bass total length decreased from >80 to approximately 60 mm. Average total length showed a strong negative correlation with density for age-0 bluegill ($r=-0.71$, $P=0.03$) but not for age-0 largemouth bass.

Adult fish

We saw differential use of shad by the two adult predators, walleye and largemouth bass. Prior to introduction of shad, 80% of walleye stomachs examined contained bluegill, accounting for >85% of diet volume (Figure 7). Other diet items (primarily insects) were mostly consumed by small (<300 mm) walleye. Once gizzard shad were established, they made up greater than 60% of the volume of walleye diets. After gizzard shad were introduced to Ridge Lake, they also became an important part of the diets of adult largemouth bass, making up, on average, 36% of the food volume in all largemouth bass stomachs sampled (Figure 7). In contrast to walleye, largemouth bass of all size classes made significant use of gizzard shad, and large bass (>294 mm) continued to include crayfish and fish other than gizzard shad as a major component of their diet. Variable use of shad among size classes of bass may have been due to variations in the abundance of preferred sizes of shad for each group among years, or availability of alternate forage. For data from all years combined, volume of shad in the diets of bass from 205-293 mm was negatively correlated with volume of shad in the diets of bass greater than 343 mm total length ($r=-0.87$, $P=0.05$). Use of shad by bass less than 205 mm long was negatively correlated with use of bluegill by this same group ($r=-0.92$, $P=0.02$).

While we saw major changes in diet of both adult walleye and adult largemouth bass, the changes were not reflected in early adult growth of either predator (Figure 8). Mean total length of age 1 and 2 largemouth bass ranged from 175-202 mm and 237-264 mm, respectively, and did not differ between periods before and after introduction of shad (Figure 8). Similarly, mean TL of age-1 walleye did not vary (280 mm pre-shad versus 278 mm post-shad). Mean total length of age 1 and 2 bluegill ranged from 68-110 mm and 111-126 mm, and, likewise, did not differ between periods before and after gizzard shad introduction.

Survival of both walleye and largemouth bass declined significantly following the introduction of gizzard shad to Ridge Lake. For walleye, survival 12 months following stocking fell from 10% to 3%, while abundance of age-1 largemouth bass in fall population estimates fell from almost 50 fish/ha to approximately 4 fish/ha (Figure 9).

Largemouth bass predation on stocked walleye is generally low at Ridge Lake, ranging from 0-11%, 0-28%, and 0-9% for small, intermediate and large fingerlings, respectively (Table 3). While overall survival of walleye declined following the introduction of gizzard shad to Ridge Lake, shad seemed to lessen predation by largemouth bass on walleye fingerlings. Prior to the introduction of shad, average mortality due to bass predation for these three groups was 7, 14, and 0%; average mortality following introduction of shad was 3, 8, and 2%. The increase in predator mortality on the large fingerling group is due to collection of a single large walleye fingerling from a bass stomach in 1992.

Data we collected did not implicate predation as a major factor influencing survival of largemouth bass. The percent of predators examined that contained age-0 bass was generally 5% or less, and in only two years did age-0 bass account for 10% or more of the volume of predator diets (Table 4). The introduction of gizzard shad may have had a slight influence on predation by adult walleye on YOY bass. In years prior to the introduction of shad, an average of 8% of walleye examined contained young-of-year largemouth bass, accounting for 8% of walleye diet volume. Following introduction of gizzard shad, 2% of walleye contained bass, and bass accounted for less than 1% of diet volume.

Both catch and harvest of largemouth bass declined markedly following the introduction of gizzard shad to Ridge Lake. Average catch rate based on directed effort before the introduction of shad was 1.00 fish/h, but declined to 0.50 fish/h following shad introduction (Figure 10). Harvest of largemouth bass was uniformly low, less than 0.04 fish/h in all years (Figure 10). Catch of walleye based on directed effort increased, from 1.40 fish/h prior to shad introduction to 2.59 fish/h following shad introduction (Figure 10). However, this increase was due primarily to high catch rates in 1991 and 1992, and catch of walleye (based on directed effort) declined sharply in 1993. Harvest of walleye was, like that of largemouth bass, uniformly low, less than 0.10 fish/h based on directed effort, with the exception of harvest in 1991-1992. Catch and harvest of bluegill differed little between pre- and post-shad introduction time periods.

Discussion

I. General

In order to be a conventionally successful fishery management tool for small impoundments, the introduction of alternate forage must lead to increases in survival and growth, as well as catch and harvest, of resident predator species. In this study, we generally saw strong negative effect of gizzard shad at lower trophic levels, weaker, indirect effects at intermediate trophic levels, and mostly negative or non-significant effects at higher trophic levels. This was probably due to increased variability and diminishing effects when carrying across several trophic levels. Within each trophic level, several pieces of evidence pointed to the potential damaging effects of forage fish introductions.

II. Lower trophic levels

We collected data concerning relative changes in the zooplankton community at Ridge Lake following gizzard shad introduction, but we did not collect data (diet) specifically linking these changes to the introduction of shad. However, the decline in cladocerans and copepods, preferred food items for most larval and juvenile fish, in combination with increases in non-preferred items (rotifers) would indicate that the decline in total zooplankton is probably due to the introduction of shad to Ridge Lake. While levels of both ichthyoplankton and zooplankton declined following the introduction of gizzard shad to Ridge Lake, densities of both are still at or above those seen in other Illinois lakes (Clapp et al. 1994). A change in zooplankton density similar to that seen in Ridge Lake can, however, influence growth and survival of larval fish. We observed declines in growth of larval bluegill following zooplankton depletion, additional evidence indicating that gizzard shad introduction negatively influenced resident fish populations. If, however, gizzard shad are introduced into a lake with abundant (i.e., non-limiting) zooplankton resources, or if zooplankton populations rebound early enough in summer following depletion by gizzard shad, shad and bluegill populations may co-exist, to the advantage of predator populations.

III. Intermediate

We collected several pieces of evidence indicating that shad negatively influence juvenile bluegill and largemouth bass. Age-0 bluegill abundance declined, while average length increased; the opposite was true for juvenile largemouth bass. This finding is similar to observations of indirect effects on largemouth bass reported from studies of threadfin shad introduction (citation); decreased total length of largemouth bass may be due to decreased abundance of bluegill, or increases in bluegill size, making them less vulnerable to largemouth bass predation. Changes in abundance of age 0 bluegill may be directly attributable to impacts of gizzard shad, or may be due to other factors (i.e., reservoir effect, inter- and intraspecific competition, stock/recruit relationships, disruption of centrarchid spawning by gizzard shad). Forage fish may compete directly for food, or may indirectly increase recruitment of other forage species by causing decreases in predation pressure on those species. Increased recruitment of bluegill, for example, may have negative consequences, such as stunting.

IV. Higher trophic levels

The potential for supplementally stocked walleye and resident centrarchids to contribute to the sport fishery of warm-water impoundments depends substantially on early survival and growth rates of these fish. Even though walleye made extensive use of gizzard shad after shad were introduced to the lake, the introduction of gizzard shad did not appear to significantly influence walleye growth at Ridge Lake, and survival of walleye was negatively affected. Similar results were observed for age-1 centrarchids. Density of forage fish other than gizzard shad (i.e., centrarchids) may be more likely to influence walleye survival. Bluegill are a major food source for both age 1 walleye and largemouth bass, and declines in age 0 bluegill abundance may have had an indirect effect similar to that seen for age-0 largemouth bass.

Variations in timing of spawning, abundance, and growth rates of gizzard shad and bluegill may subsequently impact growth and survival of predators in small impoundments. In Ridge Lake, gizzard shad occurred in bass diets during all months, but occurred most frequently and constituted the highest percent volume of food consumed during September and October. Young-of-year gizzard shad do not reach a size preferred by adult largemouth bass before late summer, and most individuals from previous year classes of shad are too large to be eaten by any but the largest bass. In 1990, gizzard shad were the primary forage item for smaller (140-204 mm) bass (77% of diet volume), but were not used by bass greater than 343 mm TL. In contrast, analysis of bass diets in 1992 showed that small bass did not use gizzard shad, while shad made up 53% of the diet volume for large bass. Variation in juvenile gizzard shad survival and growth probably results from factors similar to those affecting bluegill, including inter- and intraspecific competition for food, abiotic factors, and predation.

V. Strong manipulation

The importance of strong manipulations in whole-lake experiments involving trophic interactions has been well-documented. All evidence that we collected indicates that the introduction of gizzard shad to

Ridge Lake was a strong manipulation. Abundance of larval gizzard shad in most years was as high as that observed in other lakes in Illinois or throughout the midwest. Because Ridge Lake is a research facility and capable of being drained and refilled relatively easily, we were able to obtain actual abundance data for adult gizzard shad at the conclusion of this study. Estimates of density of adult gizzard shad based on this draining census were also comparable to abundant gizzard shad populations in the midwest.

VI. Study design problems, etc

Probably the ideal design for a study of forage fish introduction would be a before-after, control-impact design (BACI; Stewart-Oaten et al. 1986). The use of this and other study protocols has been the subject of a great deal of debate. Because gizzard shad introduction to Ridge Lake was accidental, we did not have pre-impact data at a control site similar to Ridge Lake and were not able to implement the BACI design. However, we did collect multiple years of pre- and post-introduction data, and limited our analyses in post-introduction years to life stages and year classes of fish that would have been produced or impacted only when gizzard shad were in the lake. Because we collected multiple years of data, and because evidence from a range of trophic levels all points to a similar impact of gizzard shad, we feel that the interactions we observed are applicable to small impoundments in general.

VIII. Management recommendations

Our research showed that the effects of introducing gizzard shad were in most cases negative, but may be positive depending on the target species and population attribute of interest. For example, growth of age-0 bluegill improved following the introduction of shad. Gizzard shad had no observable positive impact on catch and harvest of sport fish species in Ridge Lake, and may have negatively influenced largemouth bass catch. With this in mind, introduction forage fish to improve sportfish populations should be done only with caution and after careful consideration of management objectives. In most cases, use of gizzard shad to improve sportfish is probably not warranted. Most (80%) previous management manipulations of gizzard shad have been removal attempts (DeVries and Stein 1990); our work indicates that these removals may serve to improve fish populations in small impoundments.

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Table 1. Density and size range of fish stocked in Ridge Lake, 1987-1994.

Year	Fish species	Density (fish/ hectare)	Length range (mm)
1986	Largemouth bass	125	100-159
		64	160-299
		17	300-509
	Bluegill	543	30-79
		252	80-199
	Black crappie	967	10-79
		44	80-210
	Channel catfish	134	180-269
1987	Walleye	120	61
		65	142
		21	208
1988	Walleye	137	61
		60	144
		26	216
	Channel catfish	134	180-269
1989	Walleye	2,500	9
		120	48
		69	132
		14	186
	Channel catfish	134	180-269
1990	Walleye	5,357	9
		125	56
		42	140
		46	211
	Channel catfish	134	180-269

Table 1. continued.

Year	Fish species	Density (fish/ hectare)	Length range (mm)
1991	Walleye	7,143	--
		137	58
		71	110
		27	204
	Channel catfish	134	180-269
1992	Walleye	7,143	--
		104	69
		66	133
		20	175
	Channel catfish	134	180-269
1993	Walleye	7,143	--
		95	62
		56	150
		22	203
	Channel catfish	134	180-269
1994	Walleye	7,143	--
		120	76
	Channel catfish	134	180-269

Table 2. Average body length of zooplankton in Ridge Lake prior to and following introduction of gizzard shad.

Group	Zooplankton body length Pre-shad	Post-shad
Daphnia spp.	0.69 (0.02)	0.63 (0.01)
Other cladocerans	0.29 (0.01)	0.34 (0.004)
Calanoid copepods	0.77 (0.02)	0.80 (0.01)
Cyclopoid copepods	0.66 (0.02)	0.56 (0.01)
Nauplii	0.22 (0.01)	0.20 (0.003)
Rotifers	0.07 (0.003)	0.12 (0.002)

Table 3. Numbers of stocked walleye fingerlings consumed by largemouth bass during the first week following stocking in Ridge Lake, 1987-1994. Walleye total length (TL, mm) is mean length of fingerlings at stocking. Minimum lengths of largemouth bass included in the population estimates were based on the maximum prey:predator ratio (0.57) found for walleyes and largemouth bass in Ridge Lake. Fall population estimates are Petersen (1987-1990) or modified-Schnabel estimates (1991-1994), except as noted.

Year	Walleye mean length (TL, mm)	Minimum largemouth bass length (TL, mm)	Largemouth bass population estimate (95% C.I.)	Number of largemouth bass examined	Estimated number of walleye eaten (range)	Percent of walleye stocked (range)
1987	61	107	1,261 (903-1,826)	117	77 (55-111)	11 (8-16)
	142	249	545 (327-965)	21	42 (25-74)	12 (7-20)
	208	365	57a(--)	6	0	0
1988	61	107	1,130 (832-1,575)	256	73 (46-88)	10 (6-12)
	144	253	380 (248-608)	104	23 (15-36)	7 (4-11)
	216	379	16 (6-39)	5	0	0
1989	48	84	925 (688-1,271)	303	0	0
	132	232	712 (501-1,047)	46	89 (63-131)	23 (16-34)
	186	326	74 (44-131)	9	0	0
1990	56	98	549 (421-717)	125	79 (60-103)	11 (8-15)
	140	246	274 (199-388)	38	67 (49-95)	28 (21-40)
	211	370	9a(--)	2	0	0
1991	58	102	707 (482-1,218)	93	0	0
	110	193	639 (432-1,111)	79	0	0
	204	358	19a(--)	0	0	0

Table 3. continued...

Year	Walleye mean length (TL, mm)	Minimum largemouth bass length (TL, mm)	Largemouth bass population estimate (95% C.I.)	Number of largemouth bass examined	Estimated number of walleye eaten (range)	Percent of walleye stocked (range)
1992	69	121	316 (248-416)	43	7 (6-9)	1 (0-2)
	133	234	282 (217-390)	30	9 (7-13)	2 (1-4)
	175	307	103 (66-201)	10	10 (7-20)	9 (6-18)
1993	62	109	176 (121-297)	45	0	0
	150	263	139 (94-242)	28	0	0
	203	356	10a(--)	3	0	0
1994	76	134	249 (167-443)	47	5 (4-9)	1 (0-1)

a - Estimates based on percentage of catch.

Table 4. Predation on YOY largemouth bass and black crappie by centrarchid predators and walleye in Ridge Lake. Table sub-headings (largemouth bass, black crappie, and walleye) indicate predators on YOY largemouth bass and black crappie.

Year	Number of predators examined (# w/food)	Percent with YOY largemouth bass	Percent volume eaten
		Largemouth Bass	
1987	860 (602)	4	2
1988	1,201 (721)	4	5
1989	1,500 (789)	1	3
1990	709 (439)	<1	<1
1991	555 (256)	4	16
1992	342 (189)	5	<1
1993	522 (275)	5	3
1994	550 (280)	5	3
		Black Crappie	
1987	0	--	--
1988	93 (74)	4	3
1989	55 (48)	0	0
1990	41 (35)	0	0
1991	45 (33)	0	0
1992	27 (18)	0	0
1993	29 (16)	6	2
1994	54 (48)	0	0

Table 4. continued...

Year	Number of predators examined (# w/food)	Percent with YOY largemouth bass	Percent volume eaten
		Walleye	
1987	0	--	--
1988	51 (32)	16	10
1989	125 (69)	1	7
1990	96 (79)	2	3
1991	343 (74)	3	2
1992	149 (40)	2	<1
1993	56 (27)	0	0
1994	170 (69)	0	0

Figure Captions

Figure 1. Total zooplankton density prior to and following introduction of gizzard shad to Ridge Lake.

Figure 2. Cladoceran, copepod, and rotifer density prior to and following introduction of gizzard shad to Ridge Lake.

Figure 3. Density of larval gizzard shad and larval bluegill in Ridge Lake, pre- and post-shad introduction.

Figure 4. Larval bluegill growth prior to and following introduction of gizzard shad to Ridge Lake.

Figure 5. Larval bluegill survival prior to and following introduction of gizzard shad to Ridge Lake.

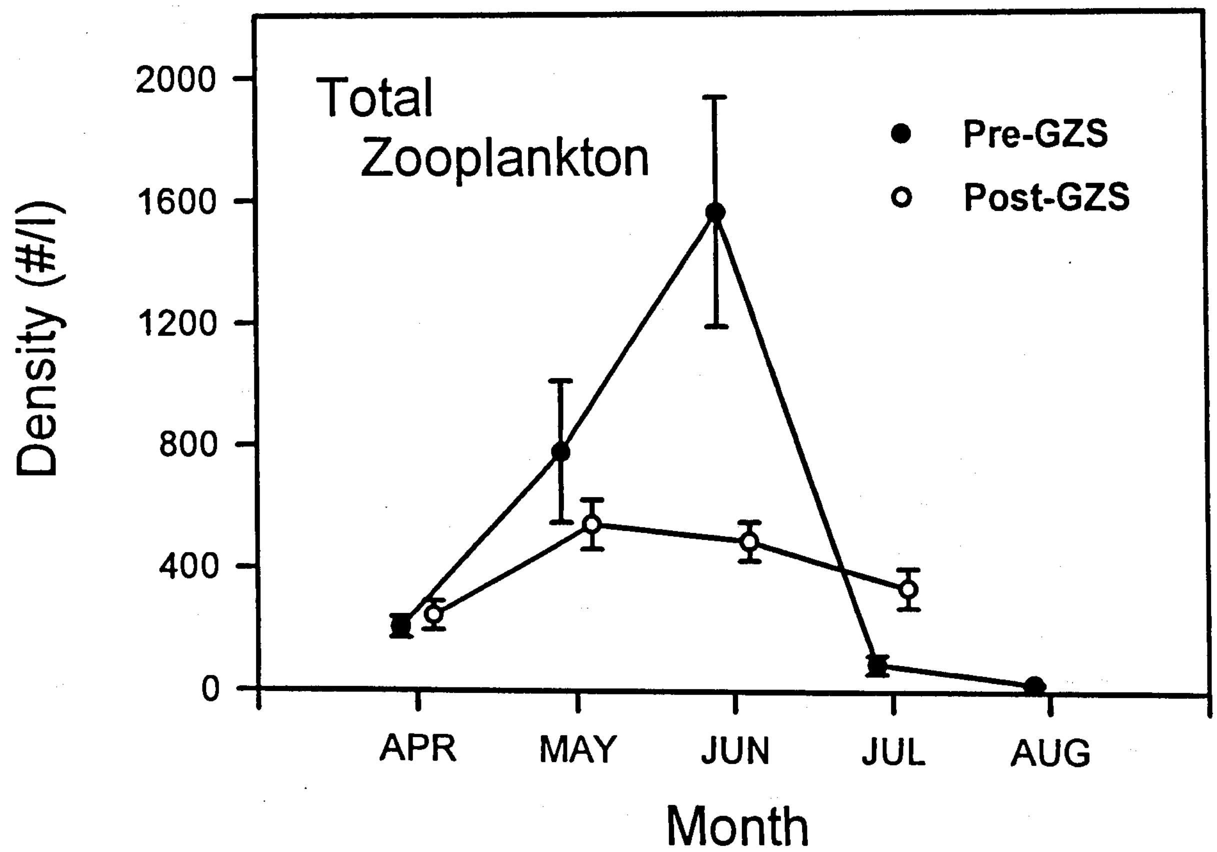
Figure 6. Abundance and growth of age 0 bluegill and largemouth bass prior to and following introduction of gizzard shad to Ridge Lake. Note different scales for densities of bluegill and largemuth bass.

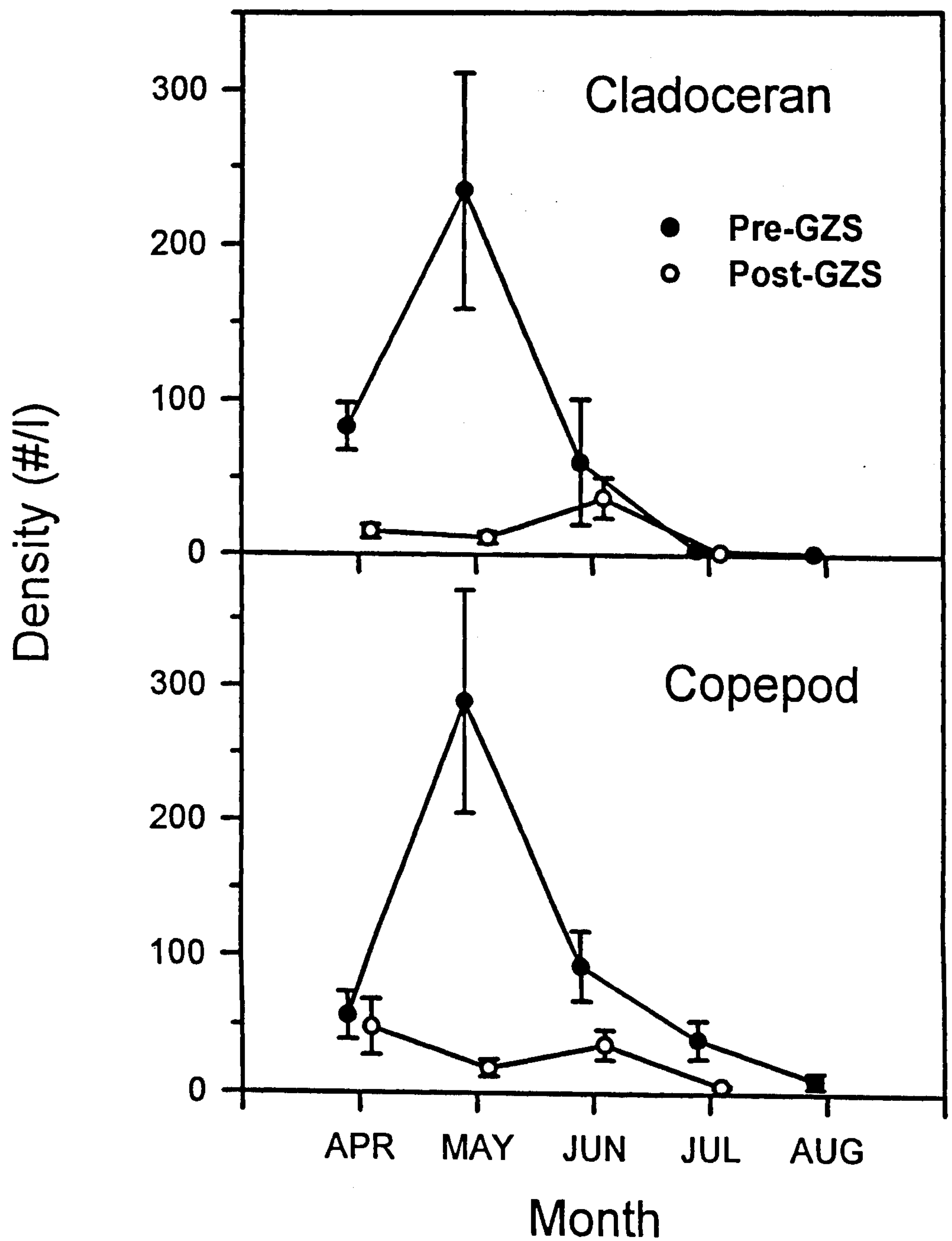
Figure 7. Diet of adult walleye and largemouth bass prior to and following introduction of gizzard shad to Ridge Lake.

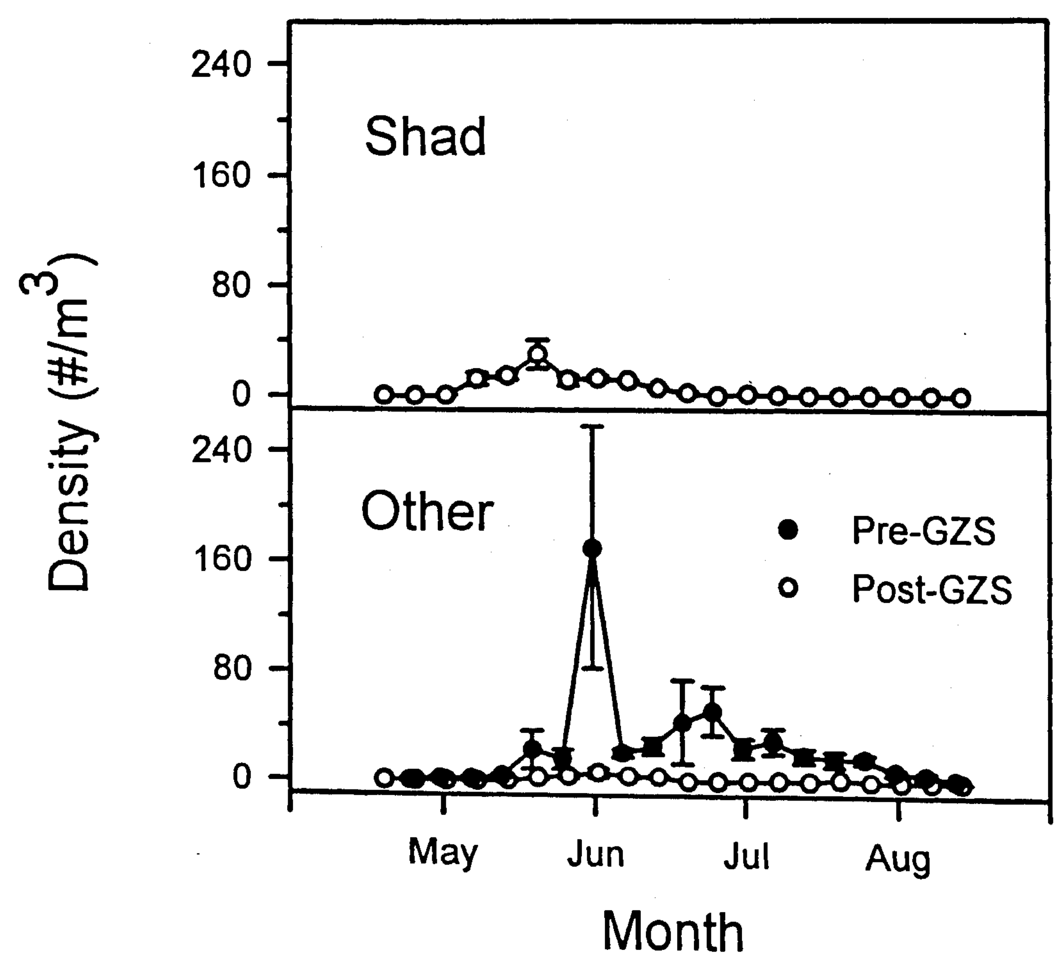
Figure 8. Growth of age 1 walleye and largemouth bass prior to and following introduction of gizzard shad to Ridge Lake.

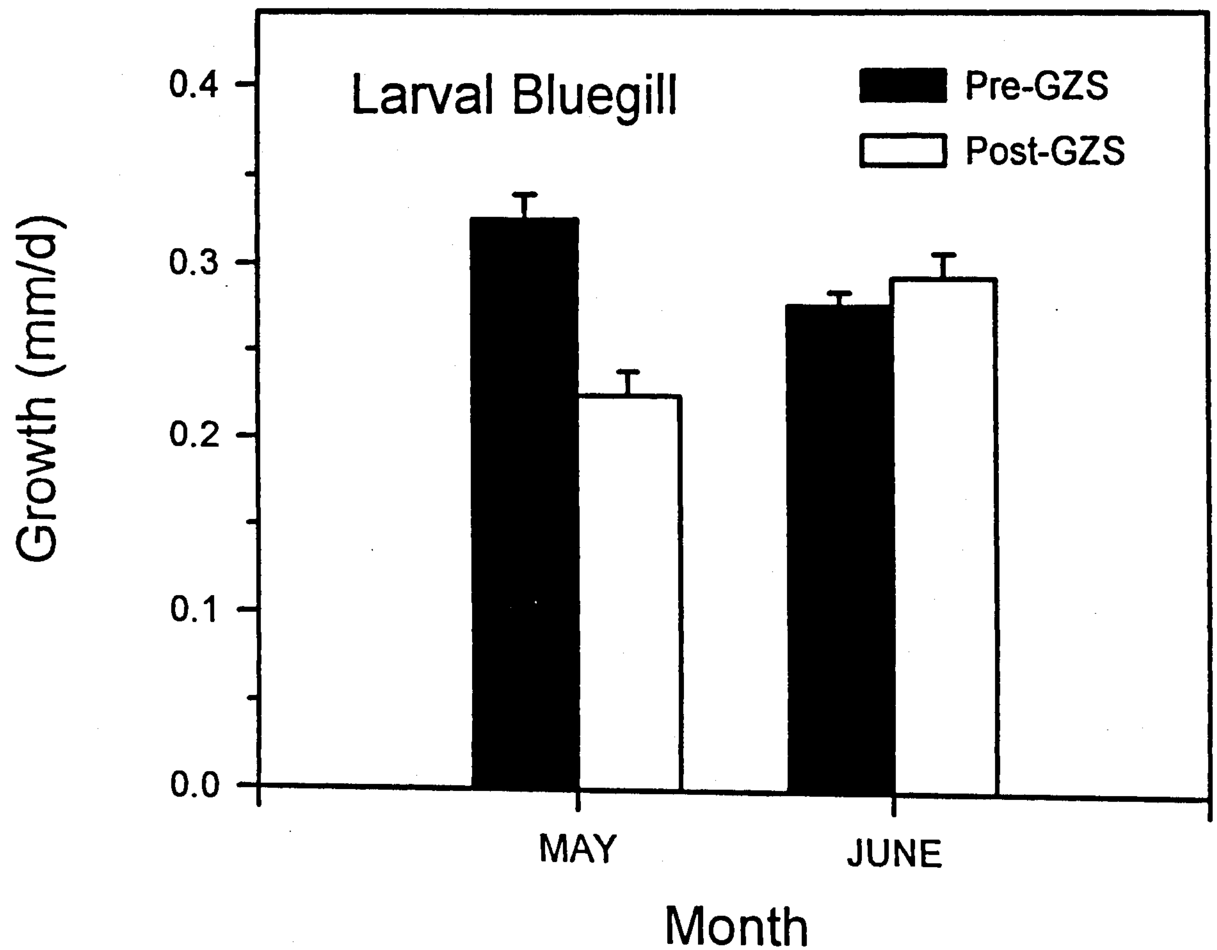
Figure 9. Survival of age 1 walleye and density of age-1 largemouth bass prior to and following introduction of gizzard shad to Ridge Lake.

Figure 10. Angler catch and harvest of largemouth bass, bluegill, and walleye prior to and following introduction of gizzard shad to Ridge Lake.

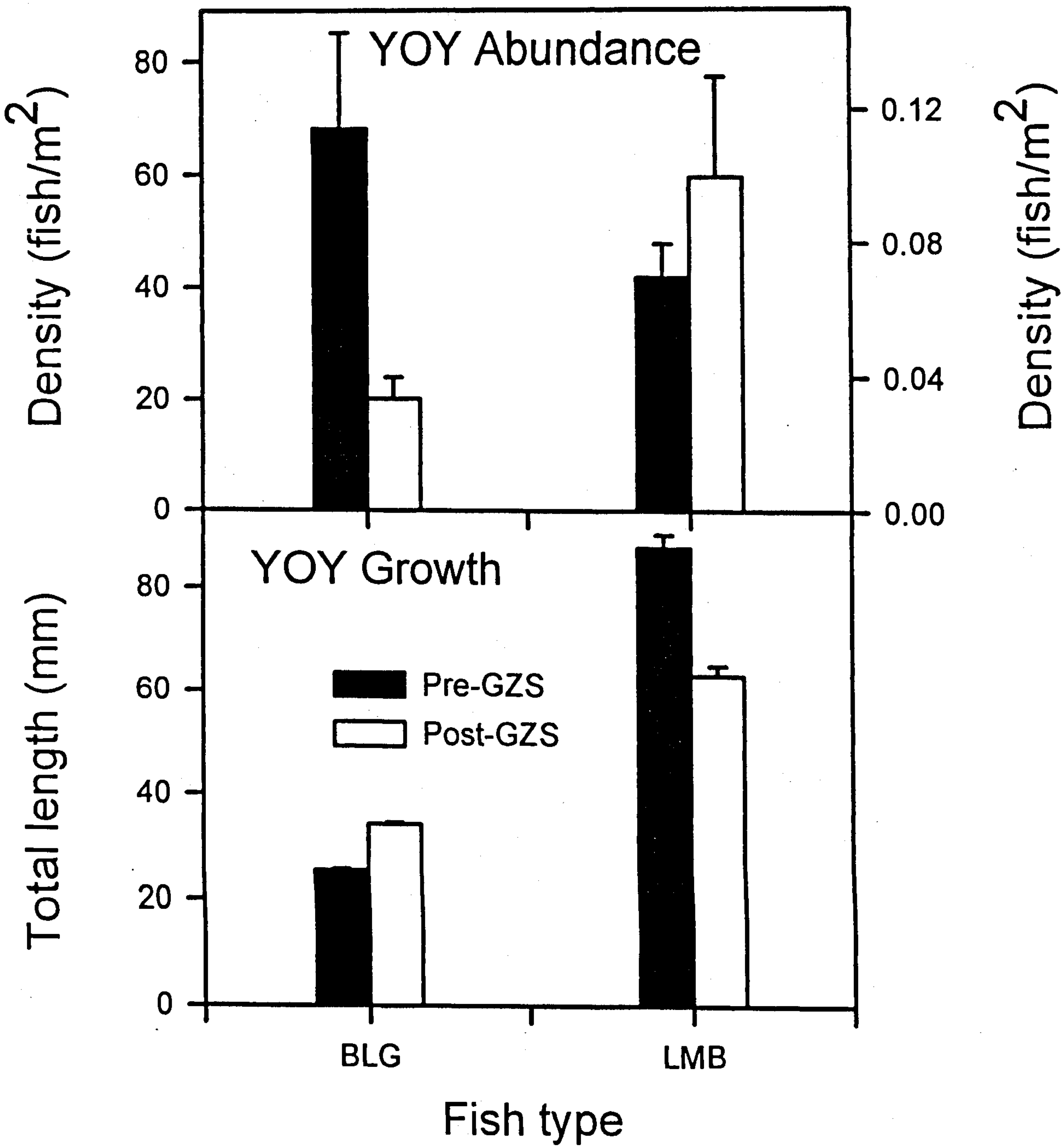

Total
Zooplankton
Pre-GZS
Post-GZS
Density (#/l)
2000
1600
1200
800
400
0
APR
MAY
JUN
JUL
AUG
Month

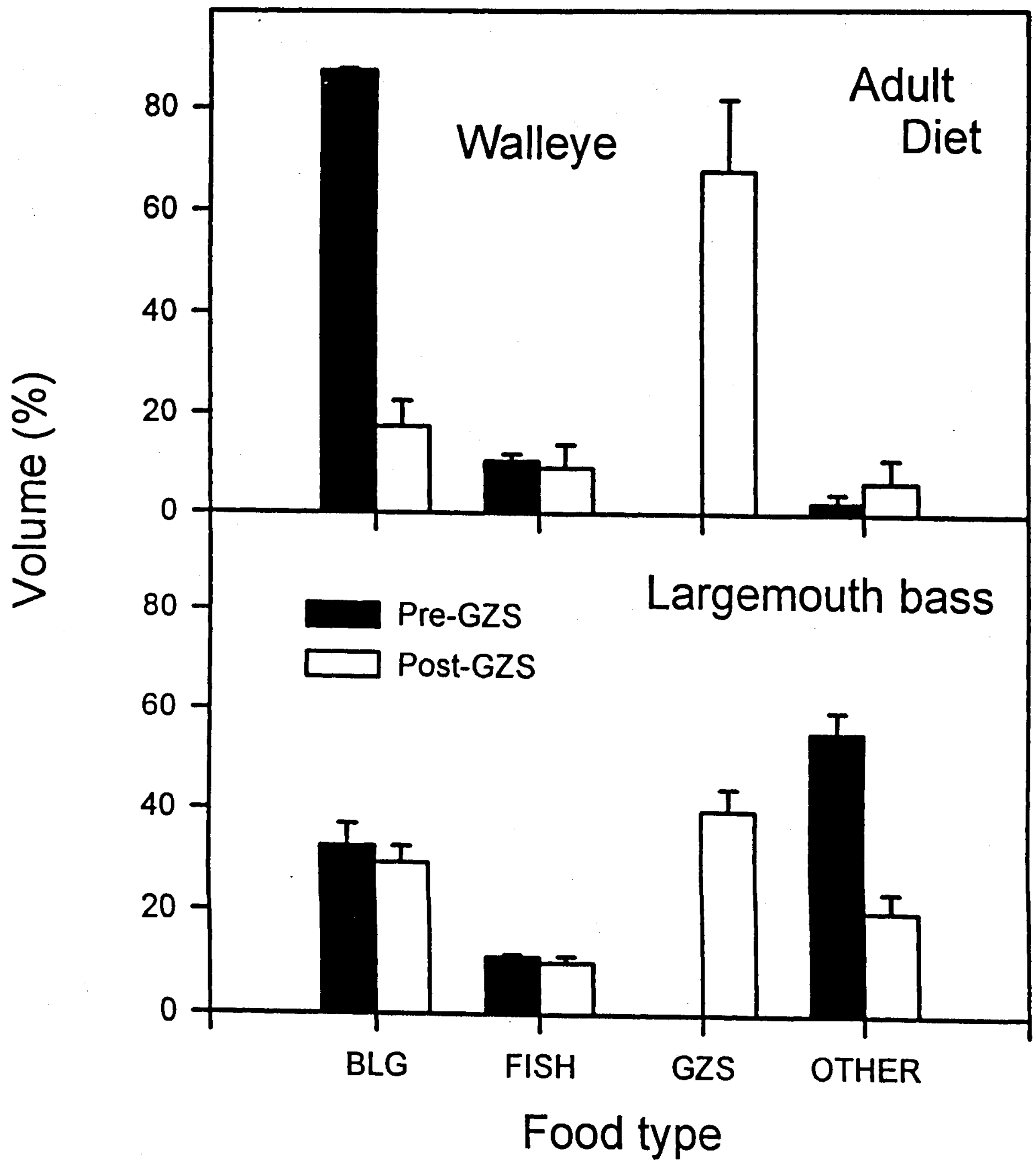

Cladoceran
Pre-GZS
Post-GZS
Copepod
Density (#/l)
300
200
100
0
300
200
100
0
APR
MAY
JUN
JUL
AUG
Month

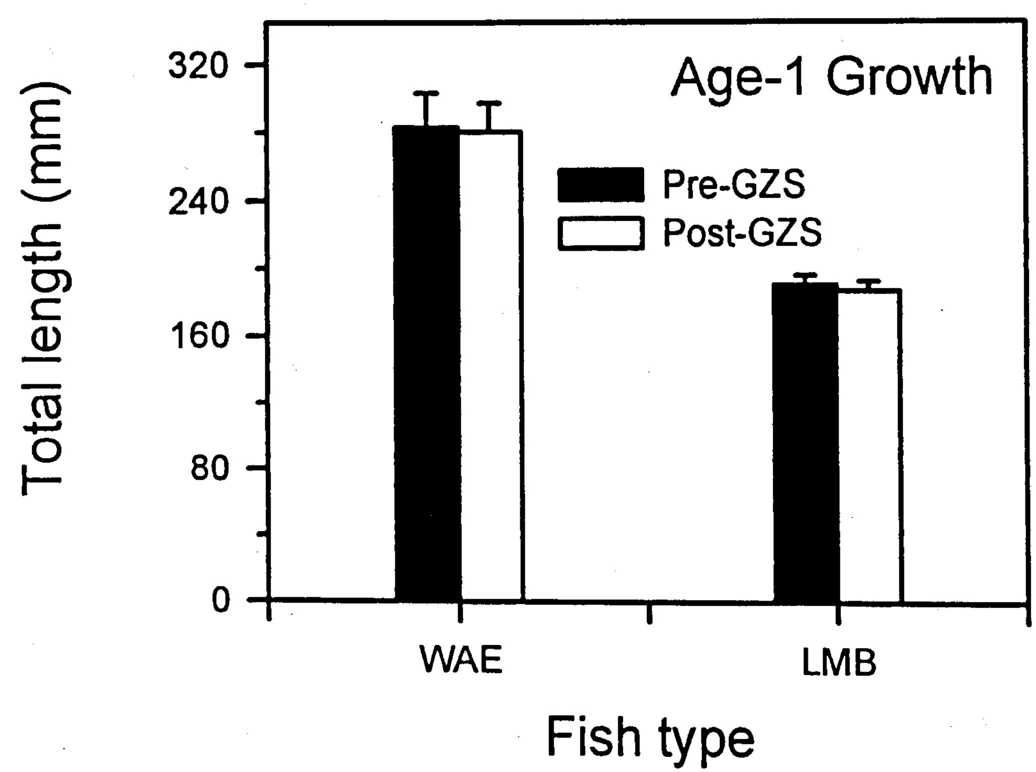

Density (#/m3)
Shad
Other
Pre-GZS
Post-GZS
240
160
80
0
May
Jun
Jul
Aug
Month

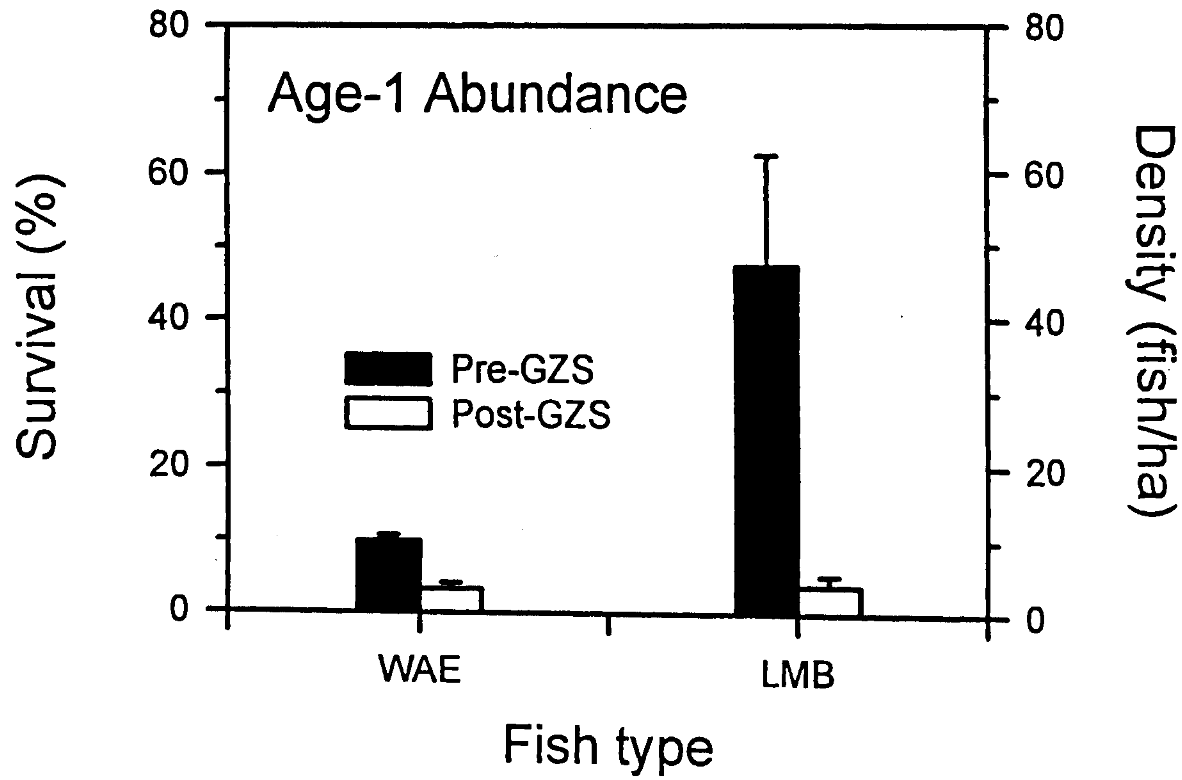


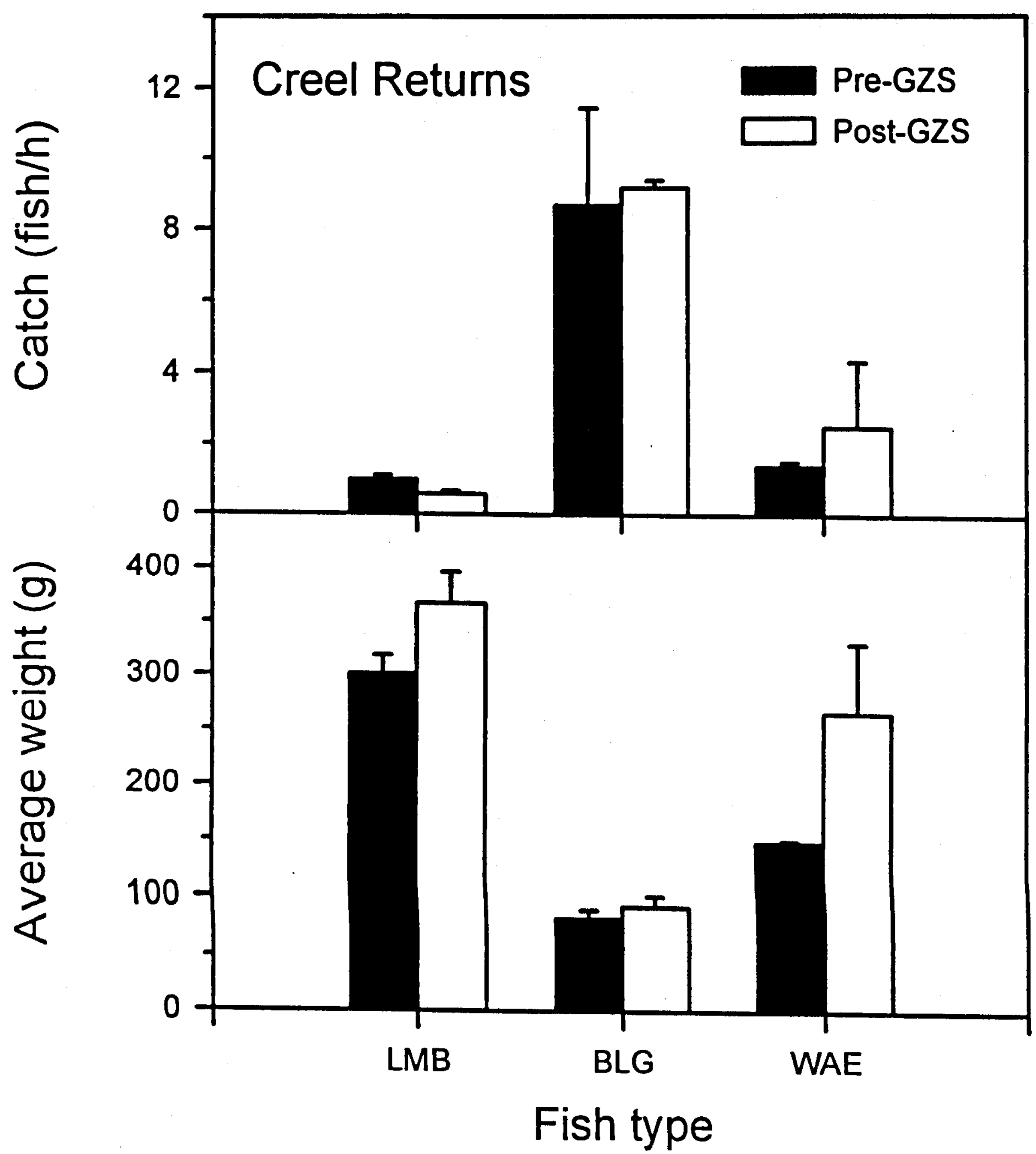
Larval Bluegill
Pre-GZS
Post-GZS
Growth (mm/d)
0.4
0.3
0.2
0.1
0.0
MAY
JUNE
Month


YOY Abundance
Density (fish/m2)
80
60
40
20
0
0.12
0.08
0.04
0.00
Density (fish/m2)
YOY Growth
Pre-GZS
Post-GZS
Total length (mm)
80
60
40
20
0
BLG
LMB
Fish type


Adult
Diet
Walleye
Largemouth bass
Pre-GZS
Post-GZS
Volume (%)
0
20
40
60
80
BLG
FISH
GZS
OTHER
Food type


Age-1 Growth
Pre-GZS
Post-GZS
Total length (mm)
0
80
160
240
320
WAE
LMB
Fish type


Age-1 Abundance
Pre-GZS
Post-GZS
Survival (%)
Density (fish/ha)
0
20
40
60
80
0
20
40
60
80
WAE
LMB
Fish type


Creel Returns
Pre-GZS
Post-GZS
Catch (fish/h)
0
4
8
12
Average weight (g)
0
100
200
300
400
LMB
BLG
WAE
Fish type